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CEDR Contractor Report 2017 - 03

Call 2012: Noise

ON-AIR Guidance Book on the Integration of Noise in Road Planning

September 2017

CEDR Call 2012: Noise

ON-AIR
Optimised Noise Assessment and Management Guidance for National Roads

Guidance Book on the Integration of Noise in Road Planning

Danish Road Directorate – DRD

Institute of Transport Economics – TOI

LÄRMKONTOR – LK

CEDR Contractor Report 2017-03 is an output from the CEDR Transnational Road Research Programme Call 2012: Integrating strategic noise management into the operation and maintenance of national road networks. The research was funded by the CEDR members of Norway, Sweden, Germany, Belgium/Flanders, the United Kingdom and Ireland. The aim of the CEDR Transnational Road Research Programme is to promote cooperation between the various European road administrations in relation to road research activities. The topics covered by this Call were developed by TG Research to fulfil the common interests of the CEDR members. The Project Executive Board for this programme consisted of:

- Vincent O'Malley, TII, Ireland (Chair)
- Barbara Vanhooreweder, Flemish Road Administration, Belgium/Flanders
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Noise barriers on Highway A9

north of Munich in Germany

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Executive summary

The objective of this ON-AIR guidance book is to present tools and guidelines which can facilitate the integration of noise abatement into the three most common planning and management situations of national road administrations, as follows:

1. Planning of new roads and motorways;
2. Planning of reconstruction and enlargement of existing roads and motorways; and
3. Maintenance and management of existing roads and motorways.

A holistic approach is applied by using the strategy of integrating noise considerations in the whole chain from strategic planning, Environmental Impact Assessment (EIA) and detailed project development to management and maintenance of road infrastructure. The earlier potential noise problems are identified, addressed and mitigated in the road management planning process, solutions and cost effectiveness of noise abatement will normally be improved. Thus, the guidance book will facilitate better noise abatement for less money.

In line with the objectives of the amended EIA Directive (2014/52/EU) [5] and the Environmental Noise Directive (END) (2002/49/EC) [14], important objectives are to support national road administrations to ensure a high level of protection of the environment and human health, and to improve living and health conditions for the many Europeans living in close proximity to major road networks. An important goal is also to facilitate improved public involvement in planning processes to support sustainable development and improved management of the road infrastructure. In a European context, public participation is fundamentally linked to the Aarhus Convention (EU Directive 1998) [6], implemented in 2001.

The guidelines are presented in this European guidance book, together with a series of illustrative examples of different measures of noise abatement. The book has been developed on the background of existing experiences and best practices used in various CEDR member countries, identified through interviews with CEDR experts and literature studies. At the same time, the guidance book stands on the shoulders of the latest European research and development projects, and takes the results of the latest CEDR noise projects (DISTANCE, FOREVER and QUESTIM) into consideration.

This guidance book is structured as a handbook, where each chapter can be read separately without reading the entire publication. For this reason, there is extensive use of cross references throughout.

As a technical background, the guidance book presents a toolbox for the road planner, working with noise issues. The toolbox provides a brief overview and background knowledge on the topic of noise assessment and offers practical tools which can aid the integration of noise as an important factor in road planning. The effects of noise and guidelines for management are included, as well as noise predictions in complicated situations such as a tunnel entrance or at highway intersections with many lanes constructed as flyovers, flyunders or bridges. Methods for assessing noise, the impact of noise on recreational activities, the overall noise effect and noise from different sources, and establishing priorities are included. Common tools for noise abatement are presented, including noise reduction at the source, under propagation and by the receiver. There is a general rule of thumb that the

most cost-effective noise abatement can be performed at the source, although noise barriers are often given priority.

The planning of new roads and improvement or extension of existing roads is one of the key parts of the guidance book. It presents how noise can be described, analysed and taken into consideration at the different stages of a road project; from the early planning where the knowledge about the project is low, through the EIA stage where different road alignments and alternative solutions are evaluated to the more detailed planning of the project where the physical framework of the project is finalised.

Road authorities have a responsibility to maintain the road infrastructure and ensure that the existing roads and road-related equipment are in satisfactory condition and that road infrastructure assets are preserved as well as possible. The guidance book presents how noise can be taken into consideration in maintenance procedures. This focusses on noise considerations during the ongoing process of maintaining pavements, as well as on maintenance of noise abatement structures such as noise barriers and earth berms. Planning and prioritisation of active noise abatement along existing roads with noise barriers and façade insulation is included, with a section on how to avoid an increase in the existing noise problems which can be caused by urban development along roads and highways, as well as increased traffic.

A significant challenge facing urban highway construction projects and construction projects near areas for recreational and holiday use is the need for planning mitigation measures of construction related noise. Although construction noise is of temporary or short-term in duration, it may adversely affect nearby property owners, residents, users and wildlife. Methods for handling construction noise are presented in the guidance book. These include tools for mitigation of construction noise and provides an insight into construction noise criteria, as well as the modelling and monitoring of construction noise. The construction phase of a road project is also one of the first occasions after the planning process where the road administration can start to build and establish a good relationship with the neighbours of a new highway.

The guidance book briefly presents how the noise mapping and noise action planning performed according to the END can be used to support work on integrating noise in the processes of planning and maintaining roads and highways. END aims to ‘define a common approach intended to avoid, prevent or reduce on a prioritized basis the harmful effects, including annoyance, due to the exposure to environmental noise’. This is in line with the objectives of this guidance book.

Public participation in the planning process represents a red line through the whole guidance book. Methods and strategies for public participation are presented in a separate chapter with a focus on positive possibilities for road administrations to initiate contact and dialogue with the neighbours of the roads. Such dialogue can facilitate good neighbour relations, thereby avoiding complaints about noise and supporting the improvement of the noise environment.

A series of interactive examples has been developed. The first part aims to provide an overview of the different methods which can be used for noise impact assessment. The second part is a tool for comparison of noise mitigation measures with results as noise maps and statistics on noise exposure. Planners can evaluate different strategies for noise abatement. The tool, which is available through the ON-AIR website, can also be used to facilitate political and public involvement in the actual planning and decision-making process.

The guidance book contains a number of annexes, presenting cost-benefit analysis (CBA) on noise and different methods for evaluating noise, as well as more than 30 practical examples of tools of noise abatement and noise management.

The guidance book is overall European in the sense that it does not only focus on concrete existing planning procedures, practices, legislation guidelines and prediction methods used in all the various countries in Europe. The guidance book may be implemented directly by professionals as inspiration and act as a tool box to supplement local national procedures, practices, etc.

The guidance book can also be implemented by being 'translated' into the national planning context of individual European countries. This can be done by using the guidance book as a reference and as a toolbox when drafting new national handbooks for the integration of noise considerations in the planning processes and road maintenance procedures of a given country.

1 Preface

The ON-AIR project "Optimised Noise Assessment and Management Guidance for National Roads" was launched in November 2013 for a duration of two years. The objective of the project was to develop tools and guidelines to facilitate the integration of noise abatement into the following three most common planning and management situations of national road administrations (NRAs):

1. Planning of new roads and motorways;
2. Planning of reconstruction and enlargement of existing roads and motorways; and
3. Maintenance and management of existing roads and motorways.

The guidelines are presented in this European guidance book, together with a series of illustrative examples of different measures of noise abatement. More information about ON-AIR can be found on the ON-AIR website (www.on-air.no). The guidance book is the final result and Deliverable D.4.1 of the ON-AIR project.

The ON-AIR project was carried out for the Conference of European Directors of Roads (CEDR). The project was selected by CEDR based on the CEDR Call 2012: Noise. The title of the noise call was 'Integrating strategic noise management into the operation and maintenance of national road networks'. The ON-AIR project addresses Project 1 of this call: 'Optimisation of noise assessment and management strategies'. To follow the work of the ON-AIR project, CEDR established a Project Executive Board (PEB) with the following members:

- Barbara Vanhooreweder, Road Administration, Belgium/Flanders;
- Helena Axelsson, Norwegian Public Roads Administration;
- Ian Holmes, Highways England;
- Lars Dahlbom, Swedish Transport Administration;
- Vincent O'Malley, Transport Infrastructure Ireland; and
- Wolfram Bartolomaeus, Federal Highway Research Institute, Germany.

Wolfram Bartolomaeus from the Federal Highway Research Institute (BASt) in Germany was the CEDR Project Manager of the ON-AIR project.

The ON-AIR project is carried out by three partners, as follows:

- The Danish Road Directorate (DRD), Denmark;
- The Institute of Transport Economics (TØI), Norway; and
- LÄRMKONTOR GmbH (LK), Germany.

Hans Bendtsen from the DRD was the coordinator of ON-AIR. The following specialists have produced this guidance book:

- Hans Bendtsen, Jakob Fryd and Jørgen Kragh, DRD;
- Christian Popp, Sebastian Eggers and Jovana Đilas, LK; and
- Anders Tønnesen and Ronny Klæboe, TØI.

2 Introduction

2.1 Background

Road traffic is the major source of human noise annoyance and adverse environmental health effects in Europe. While many environmental effects have been reduced over time, there has not been a similar reduction in noise-related effects. The population is increasingly demanding good living conditions in residential areas along roads and highways whilst expecting that the infrastructure owner should take the responsibility and bear the cost for managing noise issues. However, the budgets of road administrations are limited and the policy target is very often to get more for less.

Sustainable development and planning is important for the ongoing development of European societies, including the transport infrastructure, of which the national road networks constitute an important component. Sustainable planning includes a holistic approach covering many social, economic and environmental factors. Noise from road transport is one of these environmental factors.

Environmental Impact Assessment (EIA) according to the European Union (EU) Directive (85/337/EEC) [1] on the assessment of the effects of certain public and private projects on the environment as amended by Council Directive 97/11/EC of 3rd March 1997 [2], Directive 2003/35/EC of 26th May 2003 [3] and Directive 2009/31/EC of 23rd April 2009 [4], now codified in Directive 2011/92/EU of 13th December 2011, is an important part of road planning.

This guidance book is generally based on the existing EIA Directive, but a newly amended EIA Directive (2014/52/EU) [5] entered into force on 15th May 2014. This must be implemented in EU Member States by 16th May 2017. The new content of this directive is presented in Section 4.2 and the guidance book includes methods which will support the implementation of the new EIA Directive.

As part of the EIA Procedure [1], a variety of social, economic and environmental factors are normally investigated and evaluated. In EIA planning, noise and other factors are taken into consideration and balanced against one another. This ON-AIR guidance book particularly emphasises noise.

Public participation is an important part of modern planning. In a European context, public participation is fundamentally linked to the so-called Aarhus Convention (EU Directive 1998 [6]). This was implemented in 2001 and officially named the 'Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters'. Public participation is described throughout this guidance book and is described in detail in Chapter 8.

According to the report 'Noise in Europe 2014' [7], from the European Environment Agency (EEA), road traffic is the dominant source of environmental noise in Europe, with an estimated 125 million people in the EU affected by noise levels exceeding an L_{den} of 55 decibels (dB). Environmental noise causes 10,000 cases of premature death in Europe each year, while almost 20 million adults are annoyed and a further 8 million suffer sleep disturbance. More than 900,000 cases of hypertension are caused by environmental noise each year and noise pollution causes 43,000 hospital admissions per year.

In the NRAs within Europe, there are on-going activities related to maintaining and managing national road networks, as well as planning of new roads and the extension or reconstruction of existing roads. Today, noise is already taken into consideration by the NRAs in many ways using different national methods and planning concepts.

In 2012 and 2013, CEDR launched four research and development projects, addressing various aspects of road traffic noise and noise abatement. The four projects were as follows:

1. DISTANCE (Developing Innovative Solutions for TrAffic Noise Control in Europe) (http://distanceproject.eu/);
2. FOREVER (Future Operational impacts of Electric Vehicles on national European Roads) (http://forever.fehrl.org/);
3. QUESTIM (QUietness and Economics STimulate Infrastructure Management) (http://www.questim.org/); and
4. ON-AIR, with the purpose of developing this guidance book on integration of noise into many aspects of road planning (http://www.on-air.no/).

The main context and conclusions from these projects are summarised in the report 'Integrating strategic noise management into the operation and maintenance of national road networks – Final programme report' [8] which can be found on the ON-AIR website.

The following summary, taken from the report, provides a synopsis of the outcomes of the noise projects and their points of contact and synergies identified during the presentations and workshops at the final conference:

- "Whilst FOREVER showed predictions of future road traffic emissions in terms of changed propulsion (electric vehicles), DISTANCE investigated other changes in vehicle fleets and traffic parameters. These future prediction can be the basis for better planning procedures of future road constructions and maintenance as presented in ON-AIR.
- QUESTIM focused on the degradation of noise barriers and noise reducing asphalts, ON-AIR focused on the guidance of implementing noise mitigation in the planning of new roads and the maintenance and noise abatement along existing roads.
- DISTANCE shows the data requirements for future noise mapping and action planning deriving from the CNOSSOS-EU calculations, ON-AIR provides guidance for the support of noise mapping by NRAs and the use of the outcomes in planning and maintenance.
- ON-AIR provides a list of proven and feasible "good examples", DISTANCE focused on novel "smart noise mitigation measures".
- DISTANCE also shows a list of multi-function noise barriers and pavements with secondary uses (whether designed or "bonus"), ON-AIR provides guidance on cost-

benefit-analyses that could take those non-acoustic uses with an assigned monetary value into account." [8]

2.2 The guidance book content

The objective of the ON-AIR project is to develop tools and guidelines for managing noise in road planning. The results are presented in the current guidance book. Its purpose is to facilitate the integration of noise abatement into the following three most common planning and management situations of NRAs:

1. Planning of new roads and highways;
2. Planning of reconstruction and extension of existing roads and highways; and
3. Maintenance and management of existing roads and highways.

A holistic approach is applied by using the strategy of integrating noise considerations in the entire process, from strategic planning to EIA and from detailed project development to management and maintenance of road infrastructure. The earlier potential noise problems are identified, addressed and solved in the highway road management planning process, the better the solutions and the cost effectiveness of noise abatement. The planning tools and guidelines developed in this project will be general but can be adapted to different national contexts, regulations and procedures.

Practices and guidelines for road and construction noise can vary from country to country. This guidance book provides general guidelines and suggestions for handling noise in road planning and maintenance.

This guidance book presents key points which can considered when developing national guidance books for noise and planning. The annexes of the guidance book present various methods for cost-benefit analysis (CBA), noise evaluation and hotspot prioritisation, as well as a comprehensive series of examples of implementing different tools of noise abatement. It is up to the national practices, economy and environmental management and guidelines to include what is considered relevant at a national level at the planning stages.

This guidance book will enable objective and operational comparison of various noise-abatement measures in projects, both in terms of the number of noise-exposed people and economically. This book will facilitate achieving greater noise abatement for less money. Active use of the tools and guidance book can help to improve the living conditions of neighbours to the NRAs' road network in Europe.

The ON-AIR project and guidance book stand on the shoulders of existing best planning practice and the important European research undertaken over the past decades which has been focussed on improving the methods of noise abatement. The ON-AIR project also integrates results of the three additional CEDR noise projects, mentioned previously: DISTANCE, FOREVER and QUESTIM.

A European investigation into the various noise-planning procedures and tools, currently in use in selected CEDR countries, has been conducted. The results were presented in the comprehensive report, 'Investigation of noise planning procedures and tools', [9] focussing on appropriate examples of selected European countries' existing practices; in particular, the six countries of Norway, Sweden, Germany, Belgium/Flanders, the United Kingdom (UK) and Ireland, which funded the ON-AIR project. To provide a broader representation, Denmark, Hungary and Switzerland have also been included.

To collect information for the report, noise planning and management experts from the former mentioned countries were interviewed at sessions at LÄRMKONTOR in Hamburg, in April 2014. A Future Workshop was arranged as part of the Hamburg event, in order to develop new ideas for noise abatement and management. Furthermore, to include additional relevant information, literature was investigated as part of the development of the status report. Amongst other publications, text from the CEDR noise group was included [10, 11].

The guidance book uses a starting point of current vehicle and tyre technology as related to noise. Significant improvements in noise are not anticipated in the near future. However, in the longer term, EU requirements concerning noise emissions from new vehicles and tyres may have an effect. Electric cars generally exhibit the same noise emission as combustion cars at speeds over 30–40km/h [12, 13]. For major roads and highways, it is normally not an alternative to reduce the traffic volume, as the purpose of such roads is to create mobility and accessibility in society. Also, the purpose of major roads and highways is often to handle large traffic volumes and thus 'relieve' urban road networks. However, changing the traffic volume and reducing speed can have a significant effect on noise.

The ON-AIR guidance book on noise planning and abatement for NRAs can be used directly by the national NRAs. Another possibility is to use it as a background for developing a national guidance book, integrating the ON-AIR guidance recommendations with national legislation and planning practice. The comprehensive guidelines and methods presented in this guidance book can be used to improve the cost efficiency of noise abatement in Europe as well as to raise awareness about noise at all stages of the planning and implementation processes in road projects.

The earlier in the planning process that noise (as well as other environmental concerns, etc.) is taken into consideration, the greater the likelihood of preventing noise problems along roads and integrating the most effective measures of noise abatement in a cost-effective manner. The planning guidelines and methods presented in this guidance book can be used in actual projects to evaluate various noise abatement strategies and optimise the environmental benefit per invested Euro.

Actual calculations of noise levels will normally be performed using the relevant national calculation methods for road noise. All noise levels mentioned in this guidance book are A-weighted; for simplicity and uniformity, 'dB' is used.

2.3 Structure of the guidance book and reader's guide

This guidance book is developed as a handbook where each chapter can be read separately without going through the entire publication. Therefore, some items are presented and described in more than one chapter. Nevertheless, some cross-references exist between chapters, to keep limit repetition. The primary target audience is professionals, planning roads in NRAs, and municipal/regional road administrations, as well as consultants working in this field.

Chapter 3 is a toolbox for the road planner, working with noise issues. The chapter provides an overview and background of the topic of noise assessment and offers practical tools which can be used in the subsequent chapters on the integration of noise as an active factor in road planning. This includes the effects of noise and guidelines, as well as noise predictions. In some situations, it may be complicated to use a national prediction method, e.g. at the entrance to a tunnel or highway intersections with many lanes constructed either as flyovers, flyunders or on bridges. Such complicated situations are addressed in Chapter 3. Methods are included for assessing noise and establishing priorities, as well as the noise impact on recreational activities, the overall noise impact and noise from different sources. Finally, common tools for noise abatement are presented.

Chapter 4 describes how noise can be handled when planning new roads and the improvement or enlargement of existing roads. The main point is that the earlier noise is taken into consideration and dealt with, the cheaper and more effective the noise abatement needed will be.

Chapter 5 presents how noise considerations can be integrated into the maintenance and monitoring of existing roads. This includes a short presentation of how noise abatement along existing roads can be planned and prioritised. The chapter ends with a section on how to avoid an increase in the existing noise problems which can be caused by urban development along roads and highways.

The focus of Chapter 6 is on noise in the road construction process. Construction noise abatement is mentioned briefly in earlier chapters, but a comprehensive presentation can be found in this chapter.

Chapter 7 presents the noise mapping and noise action planning, performed according to the END [14], and can be used to support work on integrating noise in the processes of planning and maintaining roads and highways.

In Chapter 8, methods and strategies for public participation in the planning process are presented. Public involvement and communication with the public are briefly mentioned in earlier chapters, but this chapter provides a comprehensive description.

The guidance book is supported by a series of predefined interactive examples, available on the ON-AIR website. An introduction to these interactive examples can be found in Chapter 9.

The guidance book also includes three important annexes, presenting relevant evaluation tools and examples, as follows:

- Annex A presents a CBA on noise;
- Annex B describes and assesses methods for the evaluation of noise and hotspot prioritisation; and
- Annex C, as a supplement, contains more than 30 practical examples of tools for noise abatement and noise management. The examples have been selected as an illustration of the wide variety of practical noise abatement measures which have been implemented in projects throughout Europe and other countries of the world.

3 A toolbox for handling road noise

This chapter presents a series of tools and background knowledge which can be used in the integration of noise as an active factor in road planning. These tools are referred to and applied in practical planning of new and existing roads in Chapters 4 and 5. This chapter covers the following seven parts:

1. Effects of noise – annoyance, disturbance, and health (Section 3.1);
2. Noise limits and guideline values (Section 3.2);
3. Prediction of noise (Section 3.3);
4. Establishing priorities (Section 3.4);
5. Noise impact on recreational activities (Section 3.5);
6. Overall noise impact and noise from different sources (Section 3.6); and
7. Common tools of noise abatement (Section 3.7).

The END 2002/49/EC [14], relating to the assessment and abatement of environmental noise, is the main EU instrument to identify noise pollution and to trigger the necessary action both at a Member State and EU level. According to Article 1, the END aims to 'define a common approach intended to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to the exposure to environmental noise'.

The EIA [1] also aims to provide environmental protection by foreseeing and avoiding environmental issues (refer to Section 4.2). The scope of the EIA also comprises ensuring that the public is given early and effective opportunities to participate in the decision-making procedures. Public participation is addressed in Chapter 8. The majority of European countries have regulations or guidelines, describing how to perform environmental noise impact assessments (refer to Chapter 8 for further detail).

This chapter does not summarise all of the methods used in Europe; rather, it provides the basic principles for determining the noise impacts of national roads.

3.1 *Effects of noise – annoyance, disturbance, and health*

Road noise can have a broad range of effects on the population and the economy. These include the following:

- Perceived annoyance and reduced quality of life;
- Sleep disturbance;
- Impact on people's health;
- Costs related to medical care, hospitals and lost working days, which are considered a cost to society in CBA (refer to Annex A); and
- Impact on house and property values which are considered a cost to society in CBA (refer to Annex A).

The impact can occur at various locations and at different times throughout the day; people can be annoyed in the following contexts:

- When inside their home;
- When outside their home on their terraces, in gardens yards, etc.;
- When walking in the streets, shopping, etc.;
- When in public parks; and
- When at their work, school, hospital, etc.

Noise may affect people in a way where they use their home or terrace/garden differently than they would if there were no road noise.

3.1.1 Disturbance and annoyance

The impacts of noise on the population are normally investigated using questionnaires or interviews with a systematic approach which often follows the relevant International Organization for Standardization (ISO) standard for such investigations [15]. Figure 3.1 illustrates the curve generally used in the EU for describing the correlation between noise exposure at the façade of residential buildings and the percentage of the population that express being highly annoyed by noise from road traffic in surveys. This curve is based on many investigations in various European countries. A national survey may show slightly different results. It can be seen that at an L_{den} level of 60dB, 10% are highly annoyed and at approximately 70dB, 25% are highly annoyed. The noise level has to be lower than approximately 45dB before 0% are highly annoyed.

The definition of noise limits and guideline values are often a process of weighing and evaluating both the effects of noise and the cost of the required noise abatement. Noise limits and guideline values are often defined in the range between 55 and 65dB (L_{den}) [9, 10], and this is above the 45dB level, where almost 0% are highly annoyed. It must therefore be expected that noise complaints can occur even in projects where the relevant national noise limits and guideline values are followed.

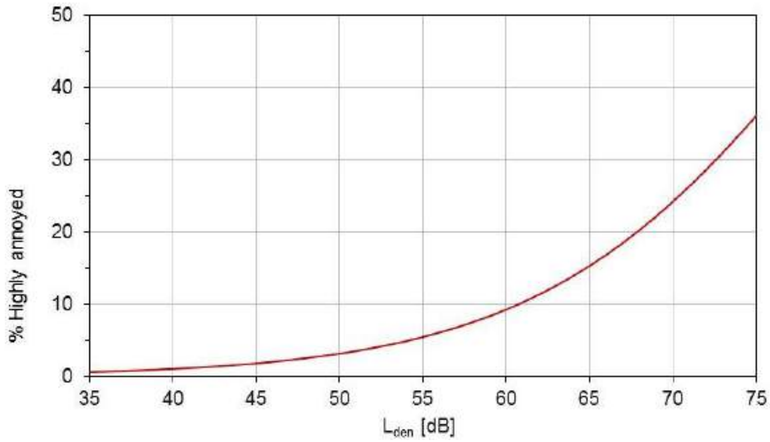

Figure 3.1: General European dose-response relation between noise exposure at the façade of residential buildings and the percentage of the population that express being highly annoyed by noise from road traffic in surveys [16].

3.1.2 Health impacts

Beyond annoyance and sleep disturbance, the health impacts of noise should also be considered. The World Health Organization (WHO) addressed the impacts of sleep disturbance on health in their 'Night noise guidelines for Europe' [17] from 2009. Their conclusions include that 'sleep is a biological necessity and disturbed sleep is associated with a number of adverse impacts on health' and that 'there is sufficient evidence for biological effects of noise during sleep: increase in heart rate, arousals, sleep stage changes and awakening'. However, the WHO also states that 'there is limited evidence that noise at night causes hormone level changes and clinical conditions such as cardiovascular illness, depression and other mental illness.'

In the 'Methodological guidance for estimating burden of disease from environmental noise' [18] from 2012, the WHO provides an updated overview of various methods of evaluating the effect of noise, including a step-by-step guide for calculating disability-adjusted life years (DALYs) for cardiovascular diseases and sleep disturbance. They state that 'there is now sufficient evidence that noise affects cardiovascular health.'

The exposure-response functions are discussed in detail in the publication 'Burden of disease from environmental noise' [19] from 2011. As for cardiovascular diseases, the WHO states that 'road traffic noise has been shown to increase the risk of ischaemic heart disease, including myocardial infarction' [19]. In the report, a list of threshold levels is provided for effects where sufficient evidence is available, as well as for those with limited evidence. The recommendation concluded that up to 30dB, no substantial biological effects are observed; for the range of 30–40dB, there are a number of effects on sleep; for 40–55dB, adverse health effects are observed; and noise levels above 55dB should be considered increasingly dangerous for public health [17]. The recommendation of the WHO for the protection of public health is a night noise level of no more than 40dB L_{night} outside of buildings with an interim target of no more than 55dB.

Another overview of health impact assessment can be found in 'Noise in Europe 2014' [7], published by the European Environment Agency (EEA). This report describes the 'relationships between noise exposure and health and well-being effects', including an up to date list of references on the topic.

In 'Burden of disease from environmental noise' [19], the WHO also estimates the 'environmental burden of disease' (EBD), which is expressed as DALYs, which are 'the sum of the potential years of life lost to premature death and the equivalent years of "healthy" life lost by virtue of being in states of poor health or disability' [19]. Beyond sleep disturbance and annoyance (refer to Section 3.1.1), the WHO includes cardiovascular disease, cognitive impairment of children and tinnitus in their considerations. They estimate that approximately 1.0–1.6 million DALYs are lost every year from environmental noise in western European countries.

3.1.3 Economic impact

The effects of noise also have an economic impact for society as well as individuals.

The annoyance and disturbance caused by noise from road traffic affects property prices, as dwellings with low or no road noise are more attractive than dwellings with a high exposure to noise [20,21,22,23]. Therefore, the road noise levels are reflected in the market prices of dwellings. Road noise also has an effect on the public valuation of properties, and in this way, on the revenue collected in the form of property taxes. Noise abatement which reduces the noise at dwellings will generally result in increased property value.

The health effects of noise also have an economic impact, as there will be costs for lost working time due to sickness or even death, as well as the cost for hospitals, medicine and other health factors. The discomfort of being sick and having reduced life quality also represents a cost to society.

Annex A on CBA presents further information on the cost of noise and how such cost is used in the economic analysis of noise in road projects and other contexts.

3.1.4 Valuating and explaining noise levels and noise level changes

A noise impact assessment of a new road project, for example, must ensure that it explains the existing and predicted future noise levels, the consequence (effect) of the change in noise level to the receptor and the significance of the noise levels and changes. As most people affected by noise are not well informed in the area of noise and physics, a commonly understood approach should be chosen. Table 3.1 suggests a methodology to explain the impact of changes in noise levels in words.

Table 3.1: Example of how changes in noise impact may be explained in words.

Extent of Noise Impact	Noise Impact Magnitude
>10dB	Severe
5–10dB	Substantial
3–5dB	Moderate
1–3dB	Slight
<1dB	No impact

For a quantitative assessment of noise impacts, the noise level change needs to be related to the sensitivity of the receptor so that the significance of the noise level change can be determined. Hence, the significance of the noise impact at a particular receptor can be determined from the magnitude of the noise change and the sensitivity of that receptor to the change in noise.

Similar approaches can also be found, for example, for air pollution in Germany. Impacts of 25–50% of the limit value are called ‘average exposure’, while those of 90–100% are ‘high exposure’. For example, an exceedance of 10–50%, is called ‘significant exceedance’ [24].

Table 3.2 provides an example of a new bypass road, using the noise impact scale presented in Table 3.1. The traffic load (and noise) in the city will be reduced significantly, leading to beneficial effects on dwellings, recreational areas, etc. in the city. In contrast, residential and noise-sensitive areas which are located near the new road will experience the adverse effect.

Table 3.2: Example of how changes in noise impact may be quantified in an EIA for the construction of a new bypass road. Both beneficial and adverse noise effects are presented.

Effect		Dwellings	Schools	Recreational Areas	Places of Interest
Beneficial	Severe effect	10		1km^2	
	Substantial effect	13		2km^2	
	Moderate effect	67		5km^2	
	Slight effect	117		7km^2	1
	No effect	12	1	2km^2	1
Adverse	Slight effect	21		6km^2	1
	Moderate effect	12	1	7km^2	
	Substantial effect	4		0km^2	
	Severe effect	0		0km^2	

In addition to the overall noise assessments in the study area covered in an EIA, it is often relevant to use the previous methods for counting housing, etc. in smaller local areas where the noise impact can be described in more detail. The consequences of noise can also be illustrated by means of differential noise maps and a noise map with façade noise levels. Figure 3.2 illustrates a differential noise map with noise reduction due to increasing a bank of earth from a height of 6m to 12m. An example of the effect of noise reduction of a new earth bank is illustrated in Figure 3.3.

Figure 3.2: Differential noise map showing the noise reduction due to increasing a bank of earth from a height of 6m to 12m. The map displays the predicted noise reduction.

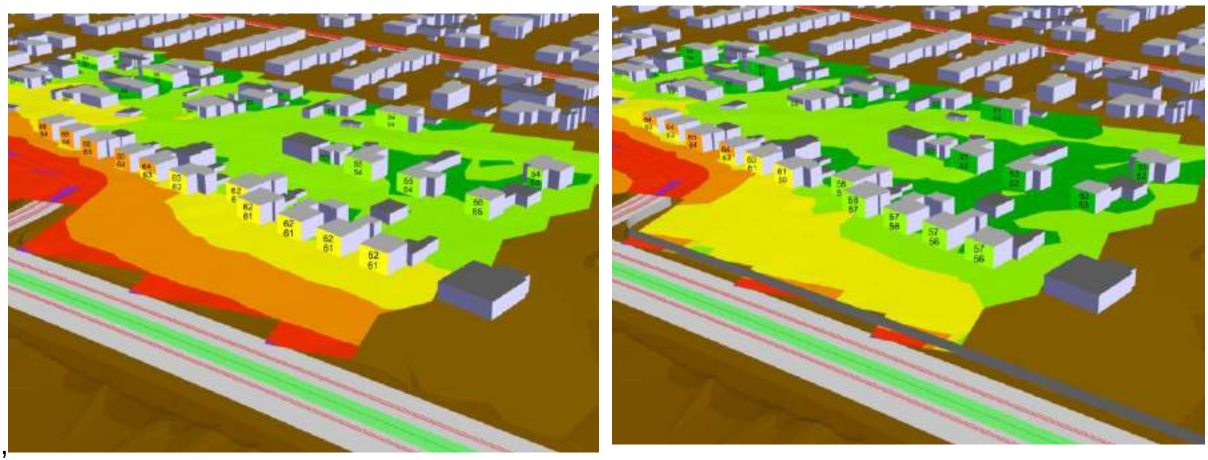

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Figure 3.3: Road noise calculations without (left) and with (right) a noise barrier along the road. The result can be used to show the significance of a noise barrier at a particular location. The grid noise map illustrate noise 1.5m above the ground, and façade noise levels at different heights are indicated as numbers on buildings.

3.2 Noise limits and guideline values

Noise limits and guideline values can be defined for various types of planning, such as the following:

- Construction of new roads and highways;
- Rebuilding and enlargement of new roads and highways;
- Construction of new buildings along existing roads and highways; and
- Building new cities where roads and buildings are planned and constructed at the same time.

This also involves the noise from the actual process of constructing a new road or highway.

The practices and legislation related to noise limits and guideline values vary amongst European countries, as follows [9, 10]:

- In some cases/planning situations, binding noise limits which are not to be exceeded are used;
- In some cases/planning situations, guideline values are used. It is generally considered good practice to follow such guidelines, but it is not mandatory; and
- Some countries have general national noise guidelines which are not binding, but for example, when they are adopted in legislation on a new road project or included in a physical plan for new residential development, they become mandatory limit values that must not be exceeded [10].

Noise guidelines and limit values can be defined for various types of land use such as the following:

1. Residential areas;
2. Areas used for offices and business;
3. Urban areas with institutions such as kindergartens, schools, hospitals, etc.;
4. Areas with summerhouses;
5. Areas with hotels/tourist facilities;
6. Areas with allotment gardens for day use and for sleepover use;
7. Areas with campgrounds;
8. Green areas and parks for public use in urban areas;
9. Green areas and parks for public use in rural areas; and
10. Rural areas that are defined as special silent areas.

Noise limits and guidelines are generally defined as L_{den} values. An L_{den} value is an ‘artificial’ average noise level over 24 hours, where 5dB is added to the noise in the evening period and 10dB is added in the night period. This method allows for people being less tolerant of noise when they are at home, and especially when they are sleeping. L_{den} was introduced by the END [14] and has been adopted in many European countries. Meanwhile, the L_{Aeq} is an average noise level over any defined period, e.g. 24 hours, with no special weighting of evening and night periods. L_{Aeq} can also be used for definition of noise limits and guidelines. Given the sensitivity of the night period, the L_{night} – introduced by END – can also be used for noise limits and guidelines. It is also possible to use a combination of these parameters as noise limits and guidelines, e.g. L_{night} and L_{den} or L_{Aeq}.

Noise limits and guideline values for buildings are normally defined at a receiver point in front of the façade of a building and can either include or exclude the reflected noise from the given building. The reflection from the building generally increases the noise level by 3dB. Noise limits and guideline values can also be defined at receiver points at terraces or gardens/yards of residential buildings, in public urban parks and in green areas for public use outside urbanised zones (refer to the previous list).

The preceding section has provided a brief overview of noise limits and guideline values in Europe. It is not at all the objective of this guidance book to define new common European noise limits and guideline values. On the contrary, it is recommended to rely on the national legislation and practices for the relevant planning situations.

3.3 Prediction of noise

Generally, the basis of assessing noise in all aspects of road planning is a prediction method. When using the same prediction method, the impacts of road traffic noise for different road projects and designs can be accurately compared.

Measurements can only describe noise levels of events which occur during the survey period. Therefore, when considering the planning phase of a new infrastructure project, it is not possible to undertake measurements as the noise source i.e. the new highway is yet to exist. Furthermore, the effects of a noise barrier, for example, cannot be predicted via measurements prior to erecting the noise barrier.

In relation to planning of new roads, noise measurements are seldom carried out by road administrations in Europe [5]. An important reason for this may be that there is some uncertainty related to noise measurements in general. This can particularly be registered at greater distances from a road. In such cases, the influence of wind and weather conditions can be considerable.

European legislations are often based on noise limits, expressed as long-term average sound levels (e.g. averaged L_{den} over a year). For calculations, this means that average meteorological effects need to be considered in the assessment methods. In the case of measurements, long-term measurements on a representative number of sites are required.

Most Europe countries have their own national noise prediction method, including national noise emission data which are implemented in accordance with national noise regulation and practices. This guidance book is intended to be used in many countries, and therefore descriptions of various national prediction methods are beyond its scope. An overview concerning the noise prediction methods used in many CEDR countries can be found in [9].

According to the END [14], noise maps to date have mainly been produced using the national noise prediction method. The EU has developed the CNOSSOS-EU (Common Noise

Assessment Methods in Europe) prediction method [25, 26] which is a common European prediction method, first intended for use in noise mapping in relation to the END.

According to the EU Directive 2015/996 of 19th May 2015 on establishing common noise assessment methods [26], the EU Member States are required to use CNOSSOS-EU methods for road noise mapping in relation to the END from 31st December 2018 onwards. It is not considered the objective of this guidance book to go into a detailed description of the CNOSSOS-EU road noise prediction method.

Noise prediction methods are developed on the background of empirical data, models for noise propagation, etc. A noise prediction method generally comprises two main parts, as follows:

1. An emission part; and
2. A propagation model.

The most important source of noise from road traffic is the tyre–road noise. For passenger cars, the tyre–road noise is the dominant source at speeds of more than approximately 35km/h, and for heavy vehicles, at speeds over 60km/h. Therefore, over these speeds, the engine noise is not dominant [27, 28].

3.3.1 Calculating noise emission

Important input parameters for the determination of the noise emission are statistics or estimates on traffic volumes of light and heavy vehicles, their speed and distribution over time of the entire 24-hour day, etc. This guidance book is intended to be used in various countries, and therefore it cannot consider the various national prediction methods.

As traffic volumes may increase over the lifetime of a road, the use of a prediction horizon is appropriate for the calculations. Further details are provided in Section 4.2.1.2.

The emission part of the prediction model is based on a standard pavement. The standard pavement type used varies from country to country within Europe, but the most frequently used pavement types are dense asphalt concrete (AC) or Split Mastic Asphalt (SMA). Generally, the national standard pavement type is used as the reference pavement in the national noise prediction method. In Europe, there are various conventions and pavement technologies applied. Some prediction models can also predict the effect of using different pavement types such as noise-reducing pavements.

Noise from all pavements increases over time [28, 29]. The increase depends on the pavement type and additional factors such as traffic volume and meteorological conditions (refer to Section 3.7).

The EU has noise regulations for type approval of new tyres and vehicles prior to their introduction to the European market. The limit values for noise have been tightened over time by the EU, and new noise limits may be introduced in the future. Over a longer period, this could affect the noise emissions for the national car fleets as new tyre types and vehicles become dominant on the road network. A prediction method normally addresses the current noise emission situation and does not take such new developments in noise regulation into consideration. Therefore, it is reasonable to occasionally verify that the emission database of a noise prediction model is still reflecting the actual situation or determine whether a programme to carry out new noise emission measurements is needed in order to include the effect of changes in regulations.

New vehicle types such as electric or hybrid cars have been introduced in Europe. As long as they only represent a minor proportion of the car fleet, they generally have no influence on the noise along roads; however, if introduced on a larger scale, such vehicle types should be integrated in the emission part of the noise prediction methods. The FOREVER project has investigated the future operational impacts of electric vehicles (EVs) [30]. It was found that CNOSSOS-EU overestimates the propulsion noise from EVs. Therefore, a correction is required in order to include EVs in the traffic flow. For this purpose, indicative correction factors have been developed.

3.3.2 Calculating noise propagation and levels at receivers

National traffic noise prediction methods are normally integrated into software packages which are commercially available on the market. This kind of software applies digital 3D models of the terrain, screening objects such as houses, barriers or other obstacles, receiver points, e.g. points on building façades, and the tracing of roads on the map as input for the computation of noise levels. Other important input parameters are statistics or estimates of the traffic volume, the traffic composition of light and heavy vehicles, the distribution on various time periods of the day, traffic speed, etc.

Noise can be predicted for points such as receiver points at house façades and also for grid calculations at a given height. Common heights for calculation vary from approximately 2 to 4m to reflect the noise levels for the ground or first floor of a building. According to the END, noise mapping is normally performed at a receiver height of 4m [10]. The present guidance book is intended for use in many countries and therefore cannot describe the various national prediction methods, as mentioned previously.

In complex cases such as receiver points adjacent to tunnel openings or highway intersections with several lanes constructed as flyovers, the application of national prediction methods may not be straightforward. The ON-AIR project addressed such situations in a comprehensive report [31].

Having examined literature and performed a few interviews, the consortium reached the following conclusions in relation to noise measurements and predictions:

1) Planning and mitigation should predominantly be based on calculations made by means of high quality software, incorporating high quality prediction models and operated by skilled personnel, based on an accurate 3-D model of the roads and their surroundings
2) The process of reverse engineering was found to be less versatile for noise mapping than anticipated, but may in some cases provide a practical way of improving noise source models and thereby increase the accuracy of noise maps. Measurements should then be made in positions close to important noise sources
3) Only in exceptional cases, however, should measurements be undertaken. Furthermore, it should be realised that measurement uncertainty is substantial. Measurements may be undertaken in an exceptional case for example there is reason

to suspect that a noise limit is clearly exceeded at a complainant's home, but even then a review of a noise calculation would be preferred instead of carrying out a noise measurement

4) If a measure such as traffic speed regulation or laying a noise-reducing pavement is taken, then its effect may be reliably estimated based on noise measurements made at the same position close to the road, before and after taking the measure, utilising the same methodology

In cases where it is indicated that calculation results do not yield true and fair assessment of traffic noise exposure, resources should be allocated to improving models and their implementation rather than in measuring noise exposure of individual dwellings.

Figure 3.4: Example of a complicated situation in relation to noise predictions. A highway intersection in the Netherlands with three levels of flyovers.

When producing noise mapping and statistics on the number of people exposed to certain noise levels, the indicators for the exposure may be the following:

1. The number of dwellings/households; and
2. The number of persons.

If the number of persons exposed is used, this can be predicted via standard factors for how many persons there are as an average in each household in the country/municipality or the district. It can also be predicted by the use of register data (as accessible) on how many people are actually living in each individual household along a given road or in a given urban area affected by noise. The END requires the estimated number of people exposed to noise at different levels [14]. In many cases, it must be considered sufficient to use the number of dwellings exposed or the number of people exposed, predicted by the use of an average number for persons per household.

There are multiple methods of distributing façade receivers along the buildings. In terms of noise mapping, the German VBEB method [32] will be used in future noise mapping, according to CNOSSOS-EU. Depending on the level of detail of investigation, a 'per window' based calculation may also be necessary, according to several national legislations. An overview including a comparison of three methods can be found in 'Noise mapping in the EU' [33].

3.3.3 Simplified noise prediction

Early planning stages often deal with possible corridor options for future road alignment. Often, the noise impact cannot be marked at a particular position on a map at this stage. However, it is possible to indicate its size by a scale line in an information box, possibly for different road configurations such as 'road in the same terrain as the surroundings', 'in cutting', and 'on embankment' (an example is presented in Table 3.3). On this basis, it is possible to simply count dwellings or size of areas which will be influenced by noise. This analysis also indicates where there may be a need for mitigation measures. As this approach uses simple geometric information, it can easily be implemented, e.g. for a buffer along a corridor.

Table 3.3: Simplified noise calculations provide an idea of the noise impact of the road in an early stage. Motorway, 50,000 vehicles a day, 12% heavy traffic, receiver height 1.5m.

Road Situation	**Distance from Road**			
	50m	**100m**	**250m**	**500m**
In same terrain	72dB	67dB	63dB	58dB
In cutting (2m)	65dB	60dB	55dB	52dB
On embankment (2m)	73dB	69dB	63dB	58dB

The necessary results can be derived from the calculation methods, which sometimes offer simplified methods for non-complex situations (such as the approach for 'long and straight roads' in the German RLS-90 [34]). Although these methods are not usually used in detailed expertise, they are often sufficient for an estimation.

Another approach can be simplified propagation calculations with noise prediction software. For the previous example, a single (long) road can be placed either on the ground, 2m on an embankment or in a 2m cutting. The model contains no further terrain or buildings; the distances can be read from grid calculations. A simple version of the Nordic Nord2000 prediction method can be downloaded and used for such simple calculations [35].

In some cases, especially with road intersections, single terrain features or relevant obstacles (as noise barriers), these methods can be limited. At this point, a simplified calculation model could also be considered. The calculations may be carried out without detailed terrain (and neither screening nor an increase with elevated roads), as well as without buildings and other shielding or reflecting obstacles. Rapid calculation is possible when obstacles or ground terrain data are not incorporated into the model.

This approach offers a more accurate result than using simple distances as presented in Table 3.3. Nevertheless, these results, i.e. limitations identified, should be used carefully in the early planning stages. The results can differ significantly from those with obstacles, possibly leading to incorrect decisions in the early planning process. When assessing necessary noise abatement, a detailed model is mandatory.

3.4 Establishing priorities

In most cases, the results of noise calculations are displayed using the results of a grid calculation; however, maps with noise levels at the façades can also be used for smaller areas.

Although a grid calculation can indicate the areas with high noise levels, this criterion is not sufficient when it comes to determining areas in which measures become necessary, for example, within the context of noise action planning. Therefore, in order to identify the noise 'hotspots', it is helpful to blend the number of people with the magnitude of the noise load. This can be done individually for the calculated façade levels, for example, according to the END noise mapping. However, a large number of calculated spots make the identification of hotspots more difficult.

For planning purposes, it can be an advantage to define methods and indicators which can sum up the 'load' of noise exposure along a given road or highway or for a given urban residential area. Based on different approaches, they can take noise annoyance or costs of noise into account; some methods use freely selectable limits to allow different 'steps' of assessment. For example, the LKZ (LärmKennZiffer, refer to Annex B) can first be applied to a higher limit of 65dB to address high noise levels and later to a limit of 55dB to address moderate noise levels.

3.4.1 Indicator methods for noise assessment

The easiest way to analyse the noise exposure or the effects of noise abatement is taking the actual number of people exposed to noise. The END requires 'the estimated number of people' for bands of values ranging from 55 to >75dB in classes of 5dB for the noise index L_{den} [14]. In some cases, however, it can be beneficial to use classes of just 1dB, as minor changes of noise may not be seen when using classes of 5dB. If the noise level for a dwelling decreases from 64 to 61dB due to the use of a noise-reducing pavement, for example, this will not be seen using 5dB classes.

Problems occur in the comparison of different noise abatement scenarios, as there are no 'hard' limits for noise exposure to be met. It is subjective determination to conclude whether a scenario where a noise load of over 75dB is avoided for five people is better than a scenario where 20 people are relieved in the range of 70–75dB.

For an easier comparison of different scenarios or local situations, and also to take the noise annoyance into account, various methods are used all over Europe. They differ widely regarding the extent to which they take people's annoyance into account. Several possible methods are presented in Annex B. Further information regarding the monetisation of noise annoyance can also be found in Annex B ('Valuations of noise benefits').

For the purpose of hotspot identification, the indicator values are calculated for each façade receiver point and then aggregated using different spatial methods. The methods represented in this guidance book (and in Annex B) are based on different approaches for weighting the noise loads.

The easiest approach would be the pure exceedance of a noise limit value. In this case, the number of people over a chosen threshold, for example, is summarised. However, the result highly depends on the threshold, and rates all exceedances as equal, whether they are 1 or 10dB over the threshold.

Another approach is the weighting of the people exceeding the threshold by the exceedance. This is used, for example, in the LKZ (refer to Annex B for further information). This methods still depends on a threshold but takes the exceedance into account.

Other methods are based on dose-response relations, based on noise annoyance, health effects, depreciation of residential buildings, etc. They can differ substantially on the weighting of high noise levels.

3.4.2 Spatial aspects for hotspot identification

Without any aggregation, the results of a façade receiver calculation can be evaluated for the occurrence of high noise levels. An indicator value calculated for each façade receiver could also be used as a threshold for analysis. This can be feasible in a small-scale examination area where only a limited number of façade receivers are calculated or the number of receivers with a possible 'high' noise load is low (refer to Figure 3.5, top left).

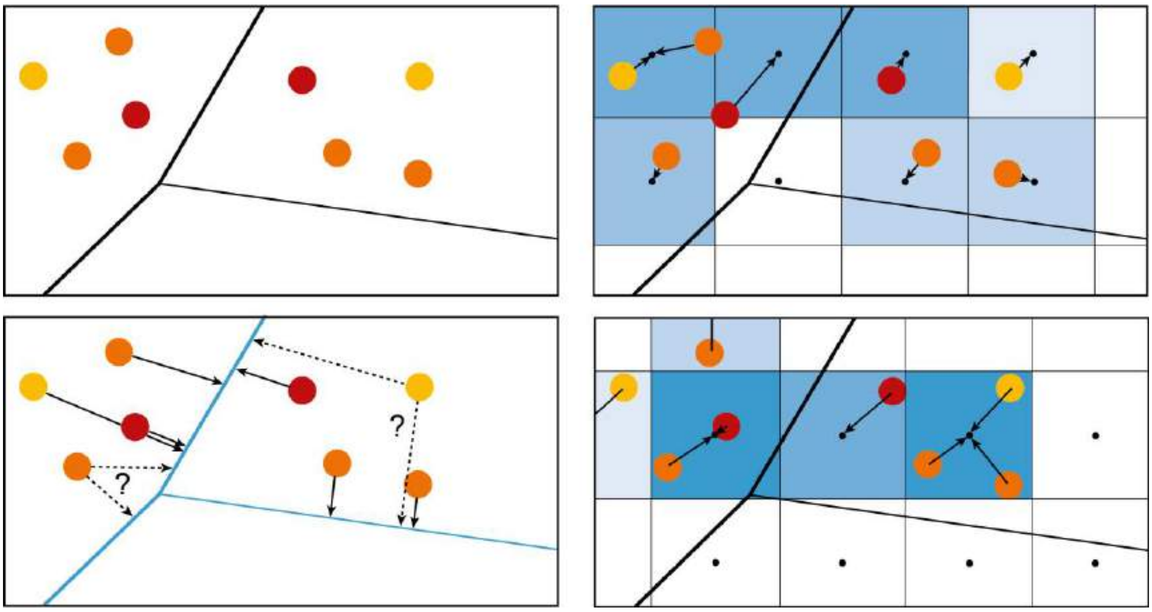

Figure 3.5: Different approaches of spatial aggregation.

The analysis for a larger area becomes more effective via an aggregation of the single receiver results. The easiest method for this is a summation by area. This could be a region, a part of a town, a building block of several houses or, generally, an evenly distributed area ('grid'), e.g. of 100m (refer to Figure 3.5, top right).

This randomly selected grid may cause highly differing results, depending on the 'origin' of the grid (refer to Figure 3.5, bottom right, and Figure 3.6). As discrete borders may cause single houses to belong to different grid areas, depending on that origin, a more robust approach could be a 'floating' summation, for example, in a circular area for a higher resolution grid (refer to Figure 3.7). As this guidance book is aimed at the networks of NRAs, some of these effects could be neglected but should always be considered.

Another approach for a summation could be the aggregation of calculated index values to the line-shaped noise sources (refer to Figure 3.5, bottom left). In cases where more than one source is present, such as in dense city areas or intersections of railway and roads, a simple assignment of the values to the 'nearest' source can lead to incorrect results. However, as long as a single source is present and this is taken into account near crossings and other intersections, it can be useful.

A variant of this method is described, amongst other methods, in 'Noise mapping in the EU' [33]. The road is divided longitudinally into segments of 100m; the number of people exposed is then summarised for each side of the road.

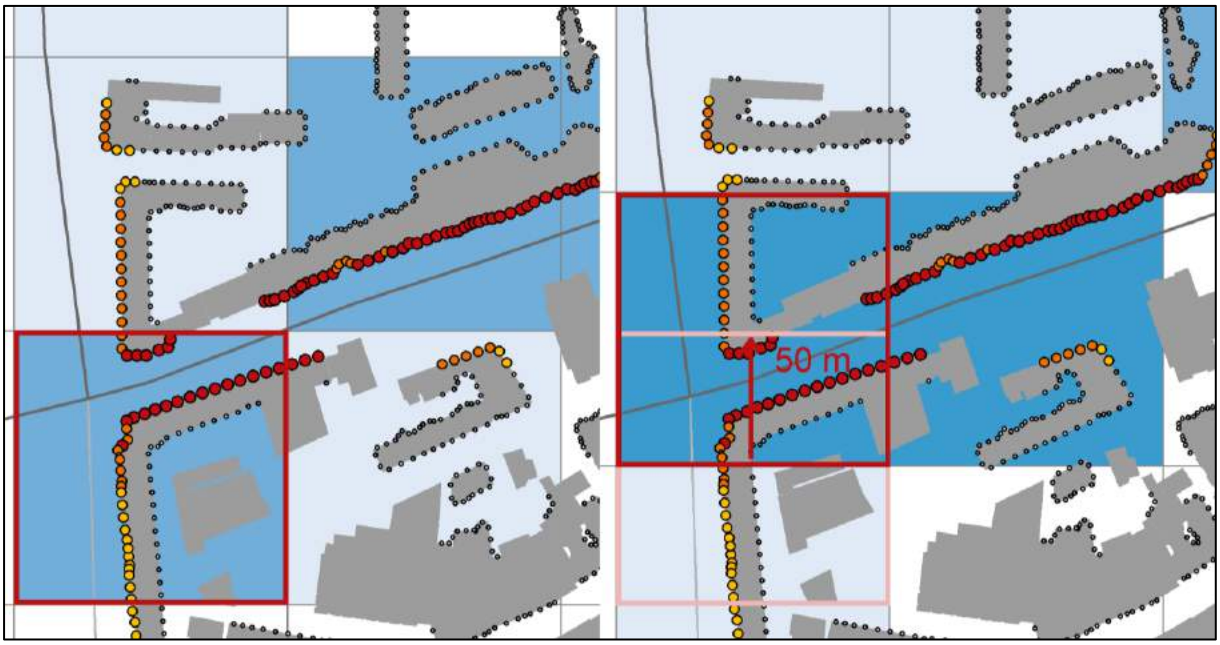

Figure 3.6: Shift of the raster origin by 50m in one direction with resulting changes of the number of noise exposed in each grid.

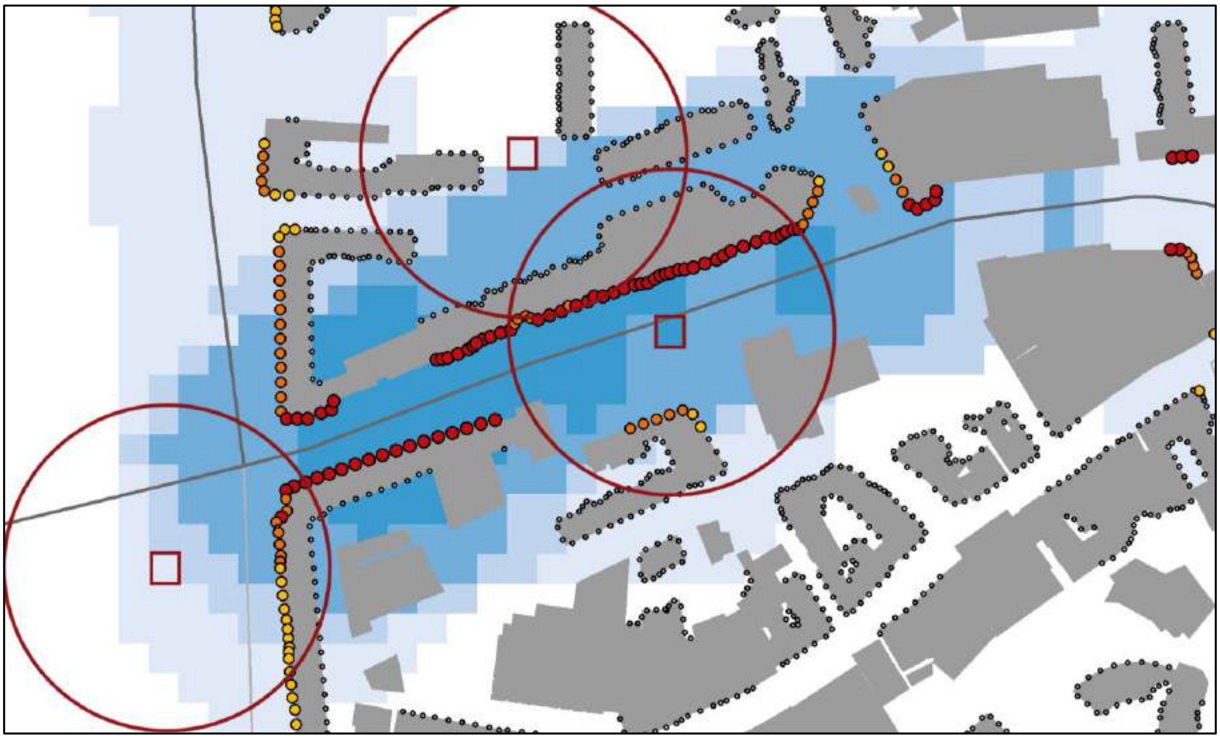

Figure 3.7: Gliding observation area – façade values allocated to several evaluation areas.

3.4.3 Comparison of indicator methods

Using different indicator methods, scenarios can easily be compared using either a single or just a few indicator values. In the example in Table 3.4, three scenarios lead to different numbers of people affected. In one instance, the overall number of people affected by 65dB is higher; in the other cases, the noise levels are lower in general for most inhabitants, but a few people are affected more intensively by levels of 70dB. To simplify the scenario, single values from the bands of the END are used, opposed to all values, e.g. between 60 and 70dB.

Table 3.4: Number of people/dwellings at certain noise levels (no intervals).

Scenario	60dB (no. of people)	65dB (no. of people)	70dB (no. of people)
1	50	120	0
2	100	50	20
3	110	30	30

Several noise evaluation methods are described in Annex B, including simple methods with the pure number of people affected by noise to methods taking annoyance and health costs into consideration. The scenarios from Table 3.4 produce the results presented in Table 3.5 using those four different approaches. As the DALY method (refer to Annex B) is based on extensive population data, it has not been included in this simple comparison.

Table 3.5: Comparison of different methods for noise exposure evaluation of the three scenarios shown in Table 3.4. The methods are described in Annex B.

Method		Scenario 1	Scenario 2	Scenario 3
Number of People Affected	>60dB	170	170	170
	>65dB	120	70	60
	>70dB	0	20	30
LKZ	Limit: 60dB	600	450	450
	Limit: 65dB	0	100	150
P-Score	Limit: 60dB	3,181	2,605	2,715
	Limit: 65dB	0	750	1,125
Noise Annoyance Index		64.8	62.4	62.4
Noise Exposure Factor (NEF)		31.9	31.0	32.2
VDI 3722-2 (% HA)		24.6	23.4	23.6
WebTAG/Noise Annoyance		41.1	41.2	42.1
UCE_{DEN}		86.3	86.6	87.0
NoiseScore		22,920	124,522	177,516

Note: The scenario with the lowest rating is highlighted in green for each method, followed by orange, and red for the highest. Decimals are used, where necessary, for distinction.

The result clearly indicates that all of the methods identify different scenarios as the best and the worst. The only similarity is that the second scenario is never the 'worst' scenario amongst the three alternatives.

For 'number of people affected', the LKZ and P-Score results depend on the limit chosen. With a lower limit, the LKZ and P-Score also prefer the second or third scenario; with a limit of 65dB, the first scenario has a lower index. This result can easily be explained by the relevance of the limit value; if a limit of 65dB is chosen, noise levels of up to 65dB are 'accepted'. Therefore, the first scenario has no people affected with regard to this limit.

The 'Noise Annoyance Index', the NEF and the VDI 3722-2 all prefer the second scenario; however, the 'Noise Annoyance Index' also prefers the third scenario with an identical indicator value result.

WebTAG, UCE_{DEN} and NoiseScore emphasise the first scenario. Particularly for the NoiseScore, the people affected by noise levels of 70dB have a much higher significance for the overall rating than most of the other methods.

The methods of LKZ, 'highly annoyed', 'NoiseScore', Bavarian 'P-Score' and Luxembourgish 'UCE_{DEN}' were also analysed in a research project for the German Environment Agency (UBA) on the optimisation of noise action planning (OptiLAP) [36]. All methods were evaluated using a town of approximately 100,000 inhabitants, providing several areas with a specific noise exposure.

The evaluation focussed on the 30 hectare areas with the highest indicator values. The result was that several groups of methods produce comparable results, although the mathematical approaches differ. Linear or mostly linear approaches as the LKZ, P-Score and UCE produced comparable results, focussing on the number of people affected. The 'highly annoyed' method generated results that focussed on the most exposed areas, while the results of the NoiseScore gave a mixture of hotspots between those of the 'linear' and 'highly annoyed' approaches.

3.4.4 Possibility for implementation in everyday planning and maintenance of national roads

As can be seen in the previous section, as well as in Annex B, the different methods presented for 'summarising' the number of noise-exposed persons or dwellings (depending on the method) can produce different results and rankings of diverse scenarios. Road administrations have to choose which method to employ. To provide a more comprehensive description of the current noise situation and the consequences of different 'packages' of noise abatement, more than one of the previously-presented methods could be used in tandem.

A hotspot analysis, together with the experience of noise experts, can be used as a basis to identify the most promising road stretches for noise mitigation. Generally, only a few variants are investigated due to the effort it takes to complete the necessary calculations. Furthermore, in most cases, the investigation is purely based on the total noise exposure. It is not investigated in detail which share is contributed by each separate noise source. Therefore, optimizations on the best use of noise reducing road surfaces, based on detailed analysis, are unlikely.

According to a literature review, interviews with members of NRAs [9] and the experience of the authors, only a few methods can result in effective analysis of the noise reduction potential of single road sections.

Different types of hot spot analysis can also prove relevant when selecting where to use, for example, noise-reducing pavements as part of the road maintenance procedures (refer to Section 5.1.1). This may be relevant if noise is to be taken into consideration as an active parameter in Pavement Management Systems (PMS).

Whenever noise is taken into account in everyday planning, the noise emission is often the only factor taken into account, without an analysis of the actual resulting noise exposure of inhabitants. This is the case in PMS, for example, in terms of the noise reduction of a road surface (refer to Section 3.7.1.1 and [29]). Calculations are required to analyse the resulting noise mitigation at receiver points.

The DRD performed an investigation on a 111km section of their network [37, 38]. The noise mapping along the network provides the number of dwellings exposed for road sections of 100m and 'can be adjusted to the actual (measured) noise emissions and used as noise exposure information'. The results of close proximity (CPX) measurements were used to adjust the model and investigate the effects of noise mitigation (Figure 3.8).

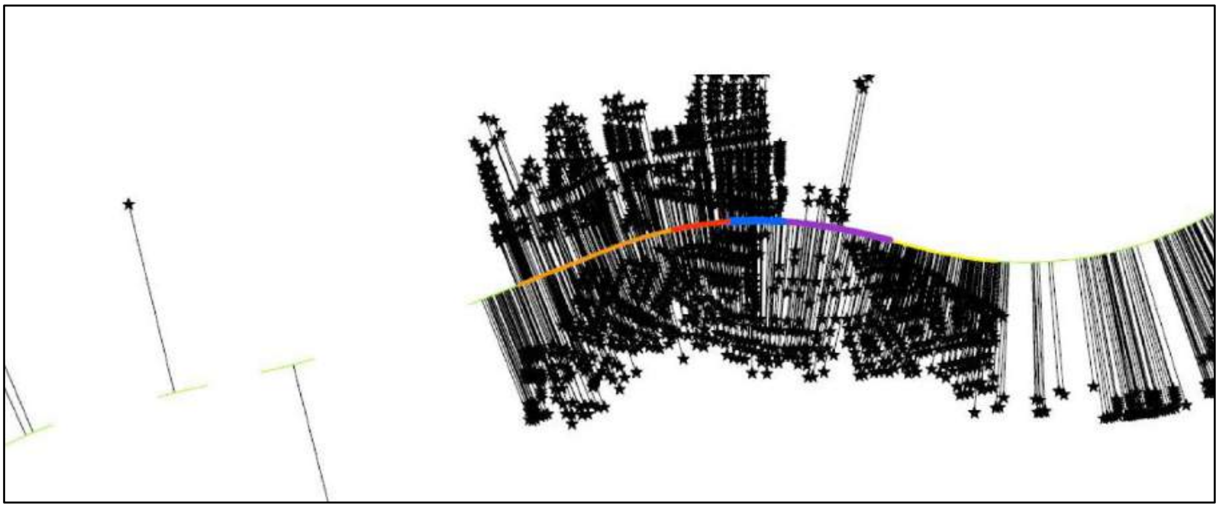

Figure 3.8: Assigning the calculated noise exposure at dwellings to 100m road stretches [38]. The black stars are dwellings. Their noise exposure of each dwelling is related to the nearest 100m road section.

CPX trailer noise measurements have been performed and stored in a database as noise source data, together with the relevant pavement information. Noise mapping at 1dB intervals has also been performed along this test road network. The noise mapping can be adjusted to the actual measured noise emissions and used as noise-exposure information. Using a price on noise exposure, expressed as price per dB per dwelling, noise-mapping data can be used to predict the yearly cost of the noise along the test road network. A simple acoustic aging model for pavements has been developed from empirical data. The aging model can be used to estimate the increase in noise exposure over the years; this makes it possible to predict the increasing cost of noise caused by the increased pavement noise emission as the pavements get older. In this way, the actual noise from pavements is converted into a cost which can be integrated into a PMS.

3.5 Noise impact on recreational activities

Guidelines for noise in recreational areas appear to be rarely implemented in Europe [9]. One reason for this may be the lack of methodology to assess the issue. The traditional approach to noise impact studies in EIAs is to focus on the noise exposure of dwellings. The number of dwellings exposed or the total noise nuisance related to people living in dwellings thus become the key parameters of the environmental assessment of noise impacts. Recreational areas, natural areas, etc. used by humans are generally not included in the quantitative assessment of noise impacts.

The DRD has developed a method for the identification and evaluation of the noise impact on recreational activities [39]. The primary result of the method is a description and assessment of the current soundscape on the site and an assessment of the site's sensitivity to changes in noise level due to a road project. Each recreational site is visited to register the following:

1. People's use of the site;
2. The existing noise sources at the site;

3. The overall soundscape on the site; and
4. The site's sensitivity to changes in noise levels.

Table 3.6: Summary of assessments of the noise impact on outdoor recreation on five different locations across a project area for three different alignments (alternatives) of a new highway. Road Alternative 1 has the least impact on the areas, while Alternative 3 has the greatest negative impact.

Site		Level of Public Use	User Expectations of Current Noise Levels at the Site	Impacts of the Recreational Activities at the Site		
#	Type			Alternative 1	Alternative 2	Alternative 3
1	Forest	Low/ Medium	Medium noise, annoying but not interfering with activities	Minor impact	Minor impact	Minor impact
2	Forest	Low/ Medium	Noisy, interferes with the activities at the site	Minor impact	Minor impact	Major deterioration
3	Forest	Low	Less noise, not annoying	Minor impact	Moderate deterioration	Moderate deterioration
4	Park	High	Medium noise, annoying but not interrupting	Minor impact	Minor impact	Major deterioration
5	Fishing lake	Medium	Medium noise, annoying but not interrupting	Minor impact	Moderate improvement	Moderate deterioration

The method is only described in Danish impact assessments of recreational areas. This approach can support the traditional noise mapping; therefore, resulting in a more holistic impact assessment of the project area.

Figure 3.9: Section of forest where a road project will have major deterioration on recreational activities. The EIA study may consider noise mitigation measures to reduce noise in the area.

3.6 Overall noise impact and noise from different sources

In some cases, it may be necessary to estimate noise from several sources. For example, in planning a new motorway which will be next or near to an existing railway, it would be appropriate to assess the overall noise impact or noise annoyance at the receivers.

The dose-response functions for road and rail are distinctly different; they are separated by approximately 6dB. This corresponds to a 6dB 'rail bonus' compared to road traffic noise. These differences are not constant, as the dose-response functions are different (and not only shifted sideways). Therefore, it is not possible to obtain an impression of the total noise nuisance by simply adding the two noise sources together.

In 2004, Miedema [40] investigated the relationship between exposure to noise from multiple sources and the total annoyance. Different methods were evaluated and a so-called noise annoyance equivalents model was suggested. Using the known dose-response curves for railway noise and road noise, it is possible to add the two noise sources together. The method can also be used for other noise sources if the dose-response curves of the current noise types are known. Some examples of annoyance equivalent to the addition of L_{den} values are provided in [41].

This method is also the basis for the German VDI 3722-2 [42], which uses the approach as a so-called 'substitute level'. In this method, the noise annoyance of road traffic noise is used as a foundation. Noise from other sources (in the VDI rail traffic and air traffic noise) is linked to this function. The method essentially involves the following steps:

1. A residential building is affected through the sources road, rail and air traffic on the façade. The noise levels (corresponding to L_{den}) are calculated for each noise source:

   Road traffic noise: 60dB

   Rail traffic noise: 65dB

   Air traffic noise: 60dB

2. The noise levels are used to determine the percentage of 'highly annoyed individuals' (% HA) for rail and air traffic. The following percentages are calculated based on the dose-response curves with the equations A5 and A6 of the VDI:

   Rail traffic: 8.6% HA

   Air traffic: 17.5% HA

3. These source-specific percentages for % HA are used to calculate the 'renormalised substitute level' related to road traffic noise (refer to VDI 3722-2 [42]). The substitute level value is the result of a correction of the determined value for % HA through the sources rail and air traffic on the road traffic value.

   By creating the relation to street traffic noise, it is possible to generate a comparable impairment value. The mentioned values presented in the example generate the following renormalised substitute levels, according to equation A8 from the VDI:

   Rail traffic: 57.9dB

   Air traffic: 66.4dB

4. The two renormalised substitute levels for rail and air traffic in energetic addition with the original rating level for road traffic (60dB) create a comparable value for the total load:

   Substitute level: 60.0dB + 57.9dB + 66.4dB = 67.8dB

5. The determined effect-related substitute level provides the basis from which to derive the % HA, according to the rating function for road traffic noise. This makes it possible to generate a conclusion regarding the 'highly annoyed individuals', through multiple exposures based on the dose-effect graph of street noise:

   Overall % HA: 20.6% HA

The VDI 3722-2 states that the calculated substitute level may not be used for other purposes than the calculation of the overall noise annoyance. The substitute level is a plain intermediate result to link the different levels of noise annoyance and is no declaration of an equivalent noise level.

3.7 Common tools for noise abatement

The following provides an overview of the most commonly used methods for noise abatement. Annex C presents more than 30 examples of how these methods have been implemented in road and building projects. Some of these approaches are also discussed in relation to different planning situations, especially in Chapter 4 on planning of new roads and Chapter 5 on management of the existing road infrastructure.

In principle, there are three stages in the 'noise chain' where noise can be reduced, as follows (refer to Figure 3.10):

1. At the source, which is the pavement, the traffic and its composition and the vehicles (refer to Section 3.7.1);
2. Under propagation from the noise source at the road to the receiver (refer to Section 3.7.2); and
3. By the receiver (buildings and outdoor areas; refer to Section 3.7.3).

There is a general rule of thumb that the most cost-effective noise abatement can be performed in earlier parts of this chain. A short overview of the noise-reducing effect of various noise abatement tools is presented in Table 3.7. The general perceived or experienced effect of the noise reduction by people is also described.

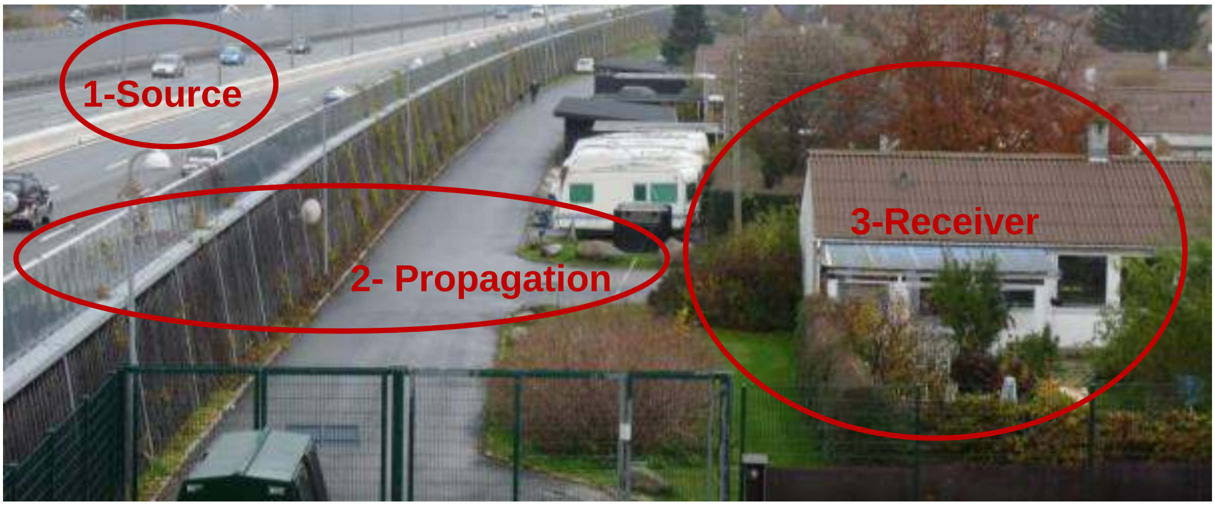

Figure 3.10: The three stages in the 'noise chain'.

Table 3.7: Examples of noise-reduction methods and values, compared to how the changes in noise level are experienced.

Noise reduction	Can be achieved by:	Changes are experienced as:
1dB	Removing 25% of traffic or reducing traffic speed by 5–10km/h	Very small change
2dB	Using noise-reducing asphalt or reducing traffic speed by 10–20km/h	A barely audible change
3dB	Removing 50% of traffic, increasing distance to the road by 100% or reducing speed by 15–20km/h	An audible but small change
5dB	Removing 65% of the traffic or using a noise berm, noise barrier or noise insulation	A considerable and clear change
10dB	Removing 90% of the traffic or using a high-noise berm, noise barrier or noise insulation	A halving of noise
20dB	Removing 99% of traffic or building a block of flats with closed courtyard areas	A very significant change

3.7.1 Noise abatement at the source

Noise abatement at the source can be achieved using two different types of measures, as follows:

1. Noise-reducing pavements; and
2. Restrictions on traffic.

There is also a third way of reducing noise emissions by introducing new regulations and limit values for type approval of new vehicles and tyres (refer to Section 3.3.1). In Europe, this represents actions taken on the political level by the EU and not the road planners. Therefore, such measures are not mentioned further in this guidance book for road planners.

3.7.1.1 Noise-reducing pavements

Road pavements have an influence on the noise emitted from the road [27]. The most important source of noise from road traffic is the tyre–road noise. For passenger cars and heavy vehicles, the tyre–road noise is the dominant source at speeds greater than approximately 35km/h and 60km/h, respectively. Above these speeds, the engine noise is not dominant.

Different surface properties have an influence on the tyre–road noise generation, as follows:

1. Smaller aggregate size reduces noise. A decrease in aggregate size of 1mm, decreases the tyre–road noise by approximately 0.25dB, all else being equal;
2. A smooth and even surface reduces noise. This can be obtained by good compaction and use of cubic aggregates;
3. An open but still smooth surface texture reduces noise. This can be obtained by increasing the built-in air void; and
4. An open porous surface structure reduces noise.

The effect of noise-reducing pavements also depends on the reference pavement which would normally be used instead. The noise from all pavements increases over time (refer to Section 3.3). The noise increase is generally higher for noise-reducing pavements than for standard reference pavements.

Figure 3.11 illustrates an example of the development of the noise from a standard (SMA 11) pavement over time; in this case with an expected lifetime of 17 years and a noise-reducing thin layer type with an expected lifetime of 12 years. The example covers a period of 51 years, equal to three lifecycles of the SMA 11. In this example, the average noise reduction for the noise-reducing thin layer SMA 6 is 2.2dB in relation to the SMA 11.

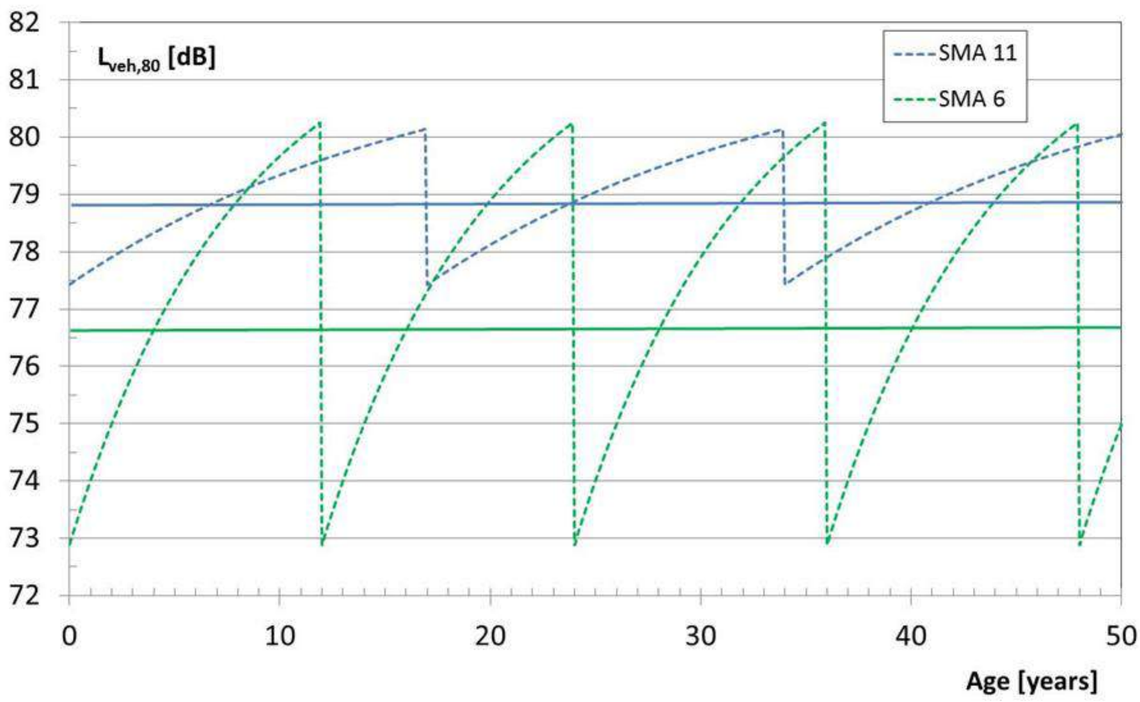

Figure 3.11: Constructed example of the development of noise over time for a SMA 11 standard pavement and a noise-reducing SMA 6 thin layer over a period of 51 years. The average noise levels over the lifetime of the pavements are shown. The average noise reduction over time is 2.2dB [43].

The lifetime for noise-reducing pavements is generally shorter than that of standard reference pavements. From a lifetime perspective, noise-reducing pavements are generally more costly than standard reference pavements.

For planning purposes, it makes good sense to use the average noise levels over time, as well as the average noise reduction. Such average noise emission levels for pavements are typically built into the emission part of the national noise prediction methods (refer to Section 3.3).

The most commonly used noise-reducing pavements are as follows:

1. Commonly called thin-layer pavements: The noise-reducing effect of thin-layer surfaces is caused by smaller aggregate sizes, sometimes with optimised mixes to make the surface semi-dense or have an open-graded surface. These pavements generally result in a lifetime noise reduction of 2 to 3dB; and
2. Single or double-layer porous asphalt which has an open porous structure and where smaller aggregates are often used: The average noise reduction produced by porous asphalt during its lifetime is typically 2dB and 4dB or more for single and double layers respectively compared to dense AC.

It must again be highlighted that the noise-reducing effect can vary and depends on the reference pavement normally used in a given situation.

Figure 3.12 illustrates an example of a newly laid noise-reducing SMA pavement with an 8mm maximum aggregate size that can be called a thin open noise-reducing layer. The pavement has a very smooth and even surface texture which reduces noise. Open cavities in the pavement surface can also be observed. These also helped to reduce the tyre–road noise.

Figure 3.12: Close up of a newly laid SMA pavement with 8mm maximum aggregate size.

Cement concrete pavements are generally considered quite noisy. However, the surface texture of such pavements can be optimised to achieve reduced noise levels.

In the EU project PERSUADE (PoroElastic Road SUrface: an innovation to Avoid Damages to the Environment) [44], prototype poroelastic pavements with a very high noise reduction have been developed and tested.

There are many reports concerning noise-reducing pavements, originating from various European countries. The CEDR working group on noise [45] is planning to publish a report summarising this knowledge. The report ‘Improving traffic noise quality along roads: Noise Reducing Pavements ’ is expected to be published in 2017 [27] on the CEDR website (www.cedr.eu). Information can also be found in references [28,43,59] and in the QUESTIM project [29].

3.7.1.2 Restrictions on traffic

Restrictions on traffic represent a series of different measures that can be used to reduce noise, including the following:

- Reducing the volume of traffic;
- Reducing the volume of heavy vehicles;
- Reducing speed;
- Reducing speed at night time (and weekends);
- Reducing traffic volume at night time (and weekends); and
- Reducing the volume of heavy vehicles at night time (and weekends).

The effect of these measures can be predicted using the national noise prediction method (refer to Section 3.3). However, there may be some clear limitations surrounding the possible use of these measures on important arterial roads. The state road network is the backbone of the major national and transnational transport corridors throughout Europe; it helps to ensure the efficient flow of traffic between European countries, regions and cities.

The mission of the NRAs is to improve mobility on the roads and help to ensure that the existing infrastructure can be used effectively. This implies that the NRAs conduct work to relieve the municipal and regional roads and direct traffic to the state's major roads, which are adapted to ensure faster and more efficient handling of traffic. However, NRAs are usually restricted from using any of these methods in various forms of traffic restrictions for reducing road traffic noise. This applies to lower speed, diversion of traffic to other roads and limitation of heavy traffic as these methods push traffic back onto the municipal and regional roads.

Reducing speed on motorways, for example, may result in significant economic costs. In Denmark, calculations have been performed on the impact of reducing the speed on one of the major approach roads to Copenhagen [9]. Analyses of the impact of a speed reduction from 110km/h to 80km/h in the evening and night-time periods on weekdays and all day on weekends, on a motorway section of 8km, indicated that the socioeconomic costs over a 10-year period were approximately €80 million (or €1 million per kilometre per year). The cost to society in this case, particularly due to increased travel time, was approximately seven times higher than the gains achieved, which included reduced noise and fewer accidents. Such cost can be taken into consideration in CBA of noise abatement and road projects (refer to Annex A). Nevertheless, there are examples from Europe where speed reductions have been considered necessary to reduce noise, e.g. in Sweden, Austria and Germany (refer to Annex C); moreover, Switzerland has a general ban, prohibiting heavy vehicles from driving on the state roads on Saturdays, holidays and during night time.

3.7.2 *Noise abatement under propagation*

Noise barriers are solid constructions, built between the motorway and the receivers along the motorway. The noise barrier between the road and houses creates an obstacle for the propagating noise, generated by traffic. The noise behind a barrier originates from the following [46] (refer to Figure 3.13):

- The sound waves over the barrier (diffraction). The sound waves have to bend over the noise barrier in order to reach the receiver, and in doing so, travel over a longer distance than they would in a situation without a noise barrier. This causes the sound level to be reduced;
- The sound waves through the barrier (transmission). A noise barrier with a sufficient sound insulation, reduces the sound waves propagating directly through the noise barrier. Their contribution to the overall sound level will thus be negligible; and
- The sound waves alongside both extremities of the noise barrier. It should be ensured that a noise barrier is long enough so that the sound passing along the sides has a lower intensity level than the sound passing over the noise barrier.

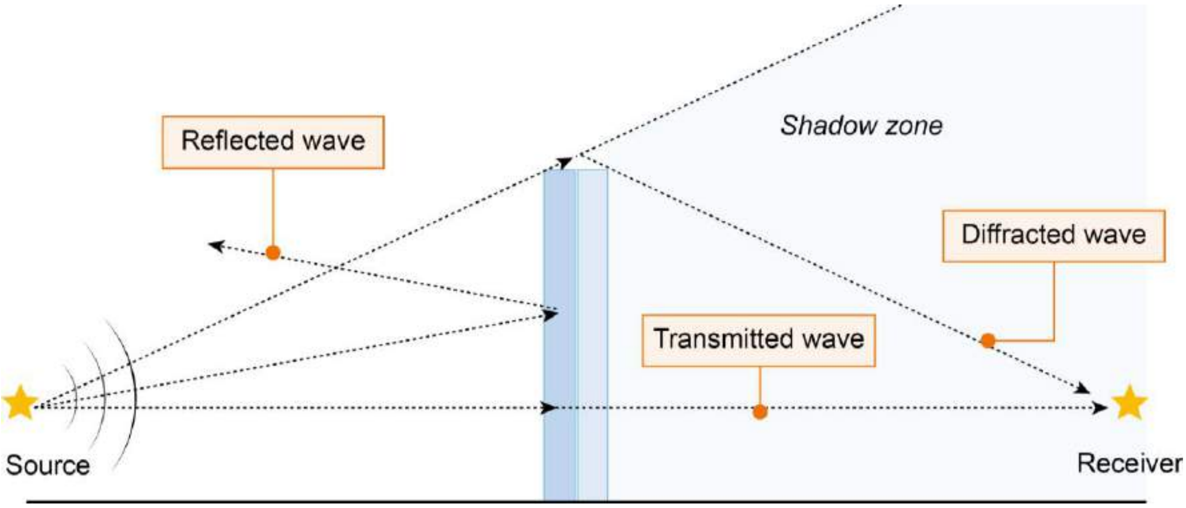

Figure 3.13: Mechanisms affecting noise barrier performance [46].

The following are some basic rules for planning noise barriers and earth walls:

- The noise barrier should be placed either as close to the road as possible or as close as possible to the residential buildings or other areas which have to be protected;
- Increasing the height of a barrier, increases the noise-reducing effect; and
- At a given point location or building in the terrain, the noise which effects this point location comes from all the sections of road that can be ‘seen’ from this point location. In order to optimise the effect of noise barriers and earth walls, it is necessary to cover all or most of the road sections which can be seen, i.e. block the line-of-sight. Therefore, if a barrier is to reduce the noise at a residential area along the road, it must be longer than the length of the residential area. A general rule is that the barrier should extend two to four times as far in each direction as the distance from the receiver to the barrier.

The following sets out some basic rules for the noise attenuation provided by a noise barrier.

1. The noise is reduced by 2dB every time the height of the barrier is increased by 1m, up to a total height of 4m; and
2. The noise is reduced by 1dB every time the height of the barrier is increased by 1m over a total height of 4m.

Further information may be found in reference [47].

Noise barriers have limitations. For a noise barrier to be effective, it must be high enough and long enough to block the view to the road. Noise barriers are of little benefit to homes situated on a hill overlooking the road or to buildings which rise above the barrier.

Openings in noise barriers for driveway connections or intersecting streets reduce the effectiveness of barriers. In some areas, homes are scattered too far apart to permit construction of noise barriers at a reasonable cost.

Noise barriers can prove effective in reducing motorway traffic noise for receivers within approximately 50–100m of a motorway; at greater distances, noise barriers have only a minor effect.

The effect of a noise barrier is greater on higher frequencies compared with lower frequencies. Lorries emit more low-frequency noise than passenger cars. Therefore, lorries are more clearly audible, even when the noise level has been reduced, following the construction of a noise barrier.

Figure 3.14 illustrates an example of the effect of a noise barrier. On the right side of the road, a 3m high noise barrier has been constructed. On the left side of the road, there is no noise barrier. The important issue concerning the effect of the barrier is that it stops the direct propagation of sound from various noise sources to the receiver. If noise levels are compared on the left and right sides of the road, one can clearly see the effect of the barrier on the block of flats.

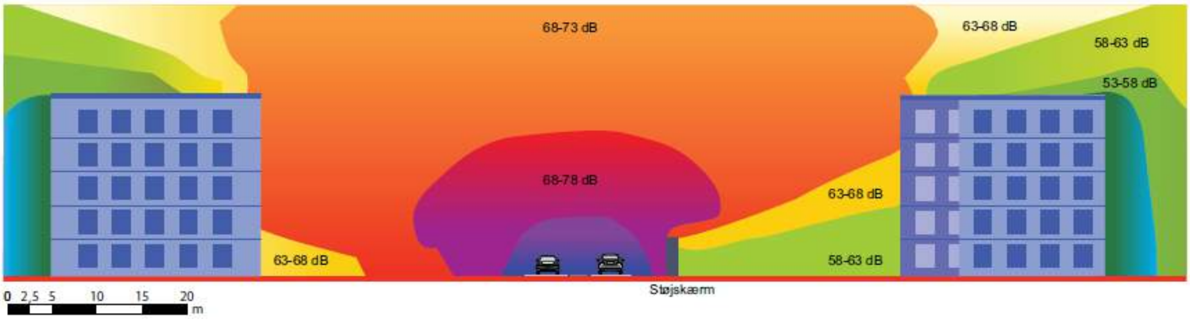

Figure 3.14: The propagation of noise with a 3m high barrier and buildings which are 20m high. 10,000 vehicles pass by on the road every day at a speed of 50km/h [9].

Both visual and acoustic considerations are relevant in the process of detailed planning of noise barriers [48]. Barriers are available in the form of noise barriers, earth berms or a combination of the two. In some cases, buildings along the road may function as a noise barrier (refer to the example in Annex C).

Figure 3.15: Long steel noise barriers with wooden slants along both sides of a motorway, protecting nearby residential areas.

Noise barriers are commonly used to reduce exposure to road traffic noise. Generally, they are not suitable in city centre locations due to the lack of space between the road and the receiver. Noise barriers are costly and are mainly used as a local abatement measure at urban areas, where many homes can benefit from the noise barrier.

Earth berms have a natural appearance and are therefore often attractive. However, due to their large footprint, tall berms require large amounts of land. Noise barriers require less space, but may involve height restrictions due to structural requirements and aesthetic considerations. Noise barriers can be made of wood, stucco, concrete, masonry, metal and other materials. Plants can be used on and around a noise barrier (refer to the example in Annex C). Noise barriers can attract graffiti artists; although some barrier material types are less likely to be subject to graffiti than others (refer to the example in Annex C). Transparent barriers may be used for aesthetic reasons and to avoid blocking the view, either from the residents and/or the drivers on the road (refer to Figure 3.16). In some countries, noise barriers also have to observe aesthetic requirements for colour and texture.

There are many types of noise barriers used in Europe. The CEDR working group on noise is planning to publish a report titled 'Improving traffic noise quality along roads: Noise barriers', which is expected to be published in 2017 on the CEDR website (www.cedr.eu) [46].

Figure 3.16: A transparent noise barrier along a motorway.

A noise barrier has two sides: one facing the road and one facing the surrounding urban environment. There can be different design requirements for both sides of the barrier (refer to the example in Annex C).

To increase the noise reduction, a barrier may also be placed at the centre of a highway, as illustrated in Figure 3.17.

Figure 3.17: High noise barriers placed both at the side of a highway and at the centre of the highway in order to increase the noise-reducing effect on a highway in Italy.

The barrier may also reflect the noise. This may have the unfortunate consequence of increasing the noise for the people living on the opposite side of a road. The level to which the noise increases on the other side of the road, depends on site conditions, the height of the barrier and the nature of the building opposite. These reflections can normally be taken into consideration in noise-prediction methods. For low, open housing areas, the noise level on the opposite side can theoretically be increased by up to 3dB, due to reflections from a barrier. Generally, earth berms do not cause noise reflections to surrounding dwellings, given their more absorbent nature.

There are various solutions to reflection issues, deriving from noise barriers, as follows:

1. The barrier can be erected at a slant so that the noise is reflected up into the air, where it will not disturb anyone;
2. Vegetation can be planted between the road and the barrier; this will disperse the noise both before and after reflection from the noise barrier. Vegetation should be as dense (all year), broad and high as possible; and
3. The noise barrier can be constructed with sound absorbent material on the side facing the road, so that reflection is reduced or entirely eliminated.

These solutions involve different visual impacts, which can affect the surroundings of the road (refer to the examples in Annex C).

The following functions, additional to noise abatement, may be integrated into noise barriers and earth walls, as follows:

- Landscaping of the urban side of an earth wall for recreational purposes;
- Designing noise barriers so they can function as a landmark for drivers;
- Designing the urban side of a noise barrier so that it improves the urban environment, e.g. by having plants growing in front of the barrier, etc.;
- Using the barrier as the side of a shelter for bikes or car parking;
- Integrating photovoltaic panels for production of electricity into noise barriers or placing them on earth walls (refer to the example in Annex C). The optimum amount of electricity is produced when photovoltaic panels are facing south and have an angle of 45 degrees in relation to the terrain. Photovoltaic panels can be placed either on the road side or on the side facing the surrounding areas. The revenue from selling the produced electricity may be used to finance or partly finance the construction of noise barriers and earth walls (more information can be found in the DISTANCE project [49]); and
- Works of art or sculpture.

In connection with the process in which a noise-screening structure is planned and designed, it is important to take into account the wishes and views of the people who live in the area. These residents will have to live with and near the screening installation every day for many years, and this may mean a perceptible change in their living conditions. It is important to ensure not to solve a noise issue and replace it with a visual problem or an impediment to movement. This can be avoided by involving the residents in the planning process (refer to Chapter 8).

3.7.3 Noise abatement at the receiver

Various measures can be used to reduce noise by the receiver, including the following:

- Noise-reducing windows and doors;
- Enhanced insulation of walls;
- Enhanced insulation of roofs;
- Noise-reducing ventilation system;
- Glass covering of balconies;
- Glass covering of windows; and
- A local noise barrier.

Façade insulation may include new windows, doors, walls, ventilation, etc.; how comprehensive this measure is, differs from country to country (refer to examples in Annex C). Unlike roadside noise barriers, façade insulation does not improve the quality of outdoor recreational areas. Façade insulation is a measure used mainly for the highest noise levels when other measures, such as noise barriers, are not an option.

Noise is primarily transmitted through the weakest points of the building. Frequently, these are the windows in a home. Depending upon the isolation quality of the existing windows, upgrading the window assemblies could provide some relief. Replacing the windows will not help significantly, if the dwellings already have high-quality windows.

In existing residences, it can be very costly to replace the majority of windows. A less expensive option, which may also produce better results, is to add a window insert to the existing windows. This is placed inside the existing window sill.

Window isolation quality is expressed as the weighted sound-reduction index (R_w), which is a number used to rate the effectiveness of a soundproofing system or material. The higher the rating, the better the isolation quality of the window. A typical dual-pane window has an R_w value of approximately 30–35 dB, while soundproof windows can achieve an R_w of approximately 40dB and special windows may achieve an R_w of 45–50dB or possibly higher.

Rather than changing all the windows of a building, another possibility is to place an extra window in front of the existing windows. Figure 3.18 illustrates an extra movable glass noise protection placed in front of an existing living room window. Figure 3.19 illustrates a façade with movable glass in front of the windows, where the noise protection was integrated from the beginning.

A more radical method of carrying out façade insulation may be to build a new glass façade in front of the existing façade (refer to Figure 3.20).

Noise abatement at the receiver may also include construction of a local noise barrier to provide noise reduction to an outdoor terrace and possibly protection to parts of the façade of the house.

Figure 3.18: Extra noise protection as a glass box placed in front of existing living room window. No noise protection has been applied to the kitchen window to the left.

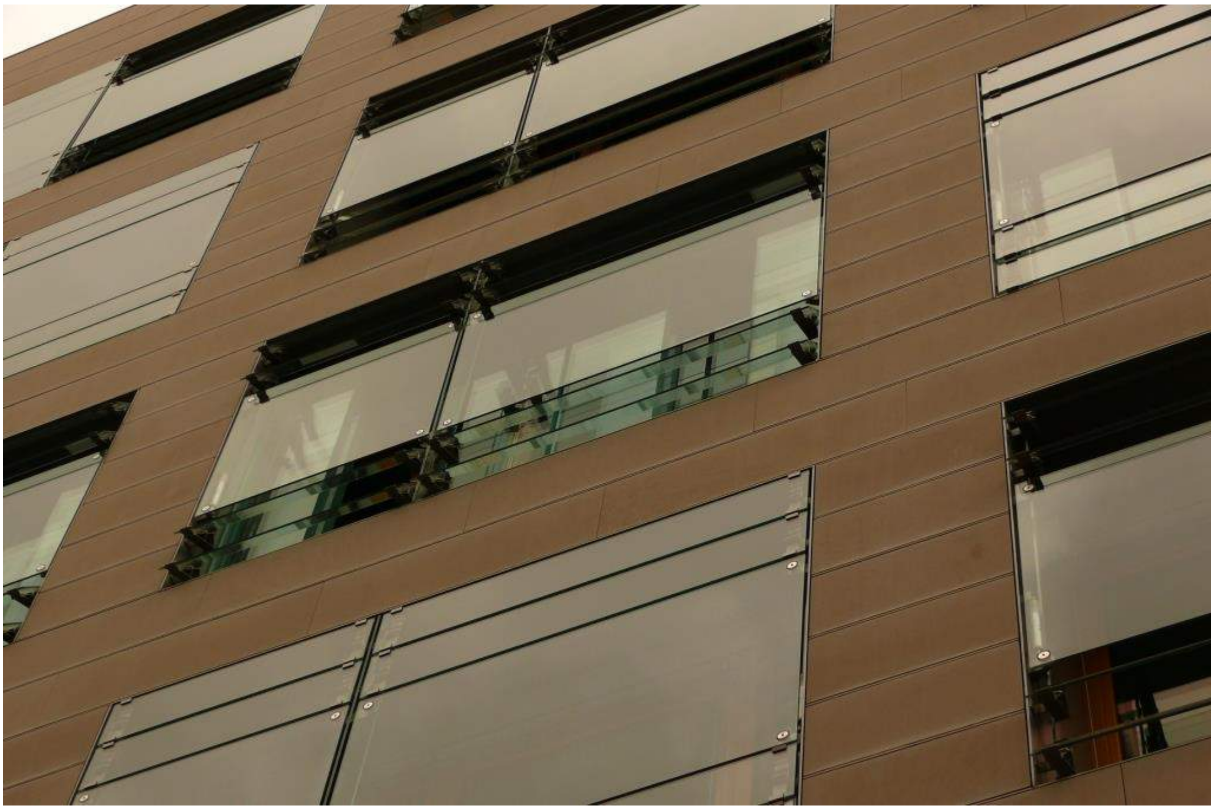

Figure 3.19: Movable glass panels in front of windows in Berlin.

Figure 3.20: New glass façade in front of the existing façade at residential building in Mexico City.

4 Planning of new roads and improvement or enlargement of existing roads

This chapter addresses how noise can be described and taken into consideration in the various stages of a road project, from the early planning, where the knowledge about the project is limited, until the more detailed planning of the project, where the physical framework of the project is finalised. It also provides various examples of how noise can be described and evaluated based on the EIAs on noise impact. The chapter is subdivided into sections, considering the following three common stages of road planning:

1. Strategic planning (Section 4.1);
2. EIA (Section 4.2); and
3. Detailed planning of road projects (Section 4.3).

It is generally the case that if noise is considered in the early stages of planning, it will be possible to integrate the more effective measures of noise abatement in a more cost-effective manner.

As previously mentioned in Section 3.7, there are three stages in the 'noise chain' where noise can be reduced, as follows:

1. At the source, which is the pavement, the traffic and its composition and the vehicles;
2. Under propagation from the noise source at the road to the receiver; and
3. By the receiver (buildings and outdoor areas).

There is a general rule that the most cost-effective noise abatement can be achieved in the earlier parts of this chain (refer to Figure 4.1) [e.g. 50]. In support of this theory, it has been empirically shown that the costs resulting from 'errors' increase by a factor 10 for each phase during which the errors are concealed and unresolved. When planning road infrastructure errors made in the early phase (such as strategic planning) are costly to solve in the detailed planning phase.

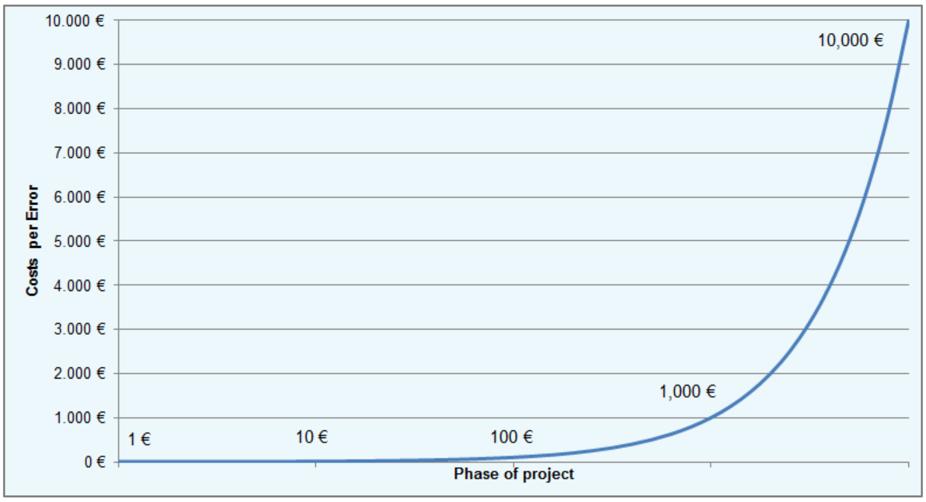

Figure 4.1: Empirical rule 'power of ten': Costs per error increase by a factor of 10 in every phase [50].

Figure 4.2: According to the principles of sustainability, the network's environmental footprint should be kept to a minimum. This often requires huge investments in noise abatement as part of new highway projects. The image shows the partial covering of a motorway in Paris.

Generally, the primary needs in the development of new roads are to improve accessibility for persons and goods, improve traffic safety and reduce travel times. While the road network must be updated to cope with future demands, according to the principles of sustainability, the network's environmental footprint should be kept to a minimum. Development of new roads affords opportunities to prevent or reduce exposure to road traffic noise through techniques such as town bypasses, ensuring sufficient distance between the road and noise sensitive areas, considering future noise issues, etc. It is therefore important that during the early stages of road planning, noise minimisation is considered during route selection processes for new roads or major realignments. As the project progresses and the design is refined through the EIA process, the ability to make major adjustments to alignments is more limited. In these studies, opportunities to prevent or reduce noise exposure are typically limited to measures such as minor adjustments to the alignment, noise barriers and noise-reducing pavements.

The planning process, while not uniform from country to country, generally consists of a set of procedural steps, culminating in a written impact assessment report (often an EIA summary report) which will allow the decision maker to determine whether to approve or reject a proposed project. Figure 4.3 provides an overview of the general stages of a road infrastructure project. Noise analysis is carried out at different stages of a road project; this is influenced by the knowledge of the project in each phase.

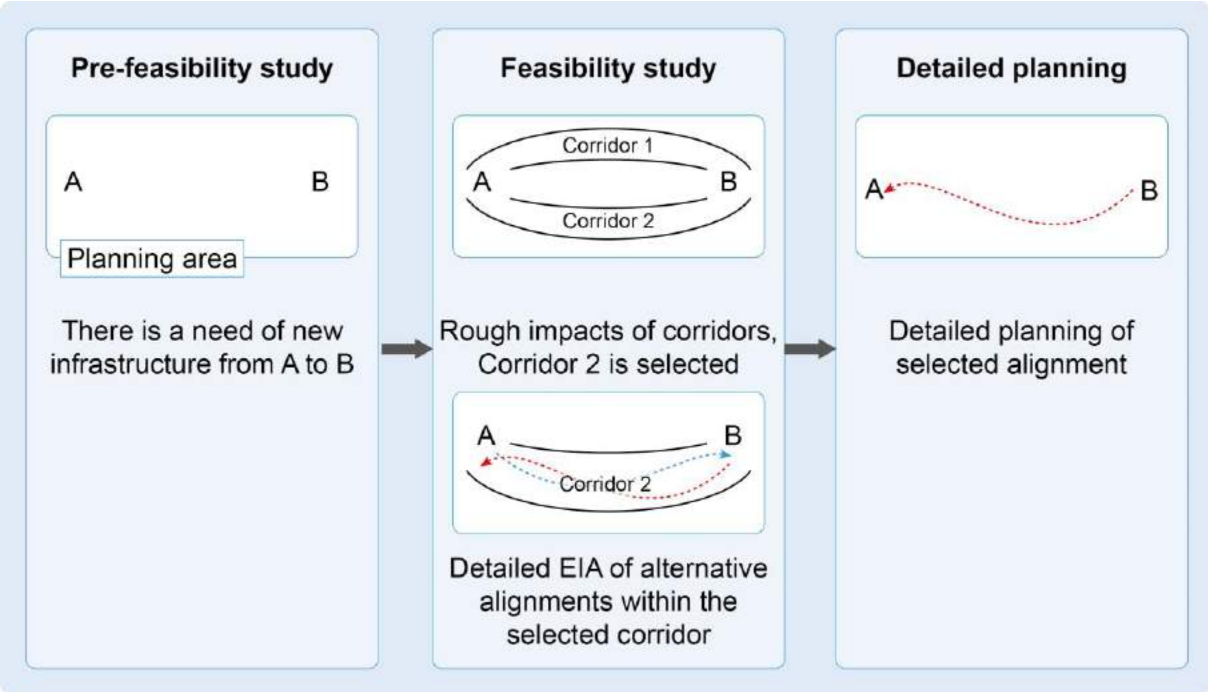

Figure 4.3: An example of different steps of a feasibility study and an EIA.

Noise is just one of many environmental factors and other relations which have to be taken into consideration in modern road planning. It will often be necessary to perform an investigation of many factors and their interrelationships to undertake a comprehensive evaluation. This is normally done in the process of performing the EIA of a road infrastructure project. However, as mentioned in the Introduction, this guidance book only deals with how noise can be handled.

4.1 Strategic planning

In the very early stage of the planning process, there is little information about the road project, such as the road alignment, traffic flow, etc. The alignment – the possible future path in the landscape – is not drawn in detail, but is often mentioned as a wider corridor in which a specific route can later be specified. In this phase, a constraint study can be carried out where all potential conflicts are analysed. The objective of the noise input to the constraints study is to identify, to a certain level, any receptors that may be particularly sensitive to noise, including dwellings, schools, hospitals, special habitats, amenity areas in common use, recreational areas and designated quiet areas.

A formal noise survey is not usually possible or necessary at this stage of the planning process. A desk-based study in relation to mapping and/or aerial photos may be an essential starting point. However, the desk study could be supplemented with a field visit by an experienced acoustician and an urban/physical planner to provide an assessment of the potential noise sensitivity of the study area. A qualitative description of the noise environment in the areas surrounding a road is normally sufficient at this stage, considering that the pre-feasibility studies also have to deal with other possible conflicts with the surroundings, including the environment, nature, flora and fauna, cultural heritage, traffic, housing, businesses, etc. Via simplified analysis, as described in the following text, it is possible to provide important input which may help to prevent noise nuisance in the environment.

Even at an early stage, there is normally some indication of traffic volumes. While the various options may exhibit differences in the precise traffic flows, an approximation will allow the zone of influence of the scheme to be estimated (using simple noise calculation tools (refer to Section 3.4.4)) in terms of the distance between the road centre line and the noise-sensitive locations (refer to Section 3.4).

An illustrative example of handling noise at early planning stages is set out below:

In a pre-feasibility study of three different road corridors as part of the strategic analysis of the long-term design of road capacity in Greater Copenhagen (refer to Figure 4.4), simplified noise calculations were carried out to provide a first general description of the noise impact in the surroundings.

The noise impact cannot be marked at a particular position on a noise map at this stage (because no route alignments will have been proposed). However, it is possible to indicate its size by a scale line in an information box, possibly for different road configurations, such as ‘road in the same terrain as the surroundings’, ‘in cutting’ or ‘on embankment’ (an example is presented in Table 4.1). On this basis, it is possible to carry out a simple counting of dwellings or size of areas which will be influenced by noise. This analysis also gives an indication of where there may be a need for mitigation measures.

Table 4.1 Simplified noise calculations indicating the noise impact of the road in an early stage. Motorway, 50,000 vehicles a day, 12% heavy traffic, receiver height 1.5m.

Road position	**Distance from road**			
	50m	**100m**	**250m**	**500m**
In same terrain	72dB	67dB	63dB	58dB
In cutting (2m)	65dB	60dB	55dB	52dB
On embankment (2m)	73dB	69dB	63dB	58dB

As another example of a methodology, the National Roads Authority in Ireland (currently Transport Infrastructure Ireland (TII)) has published a guideline with a set of graphs which can be used at an early stage to indicate the magnitude of the noise footprint for a particular road [51].

The best way to prevent future noise issues is to ensure that a new road alignment is placed at a sufficient distance from noise-sensitive areas. Another strategy is to work with the longitudinal profile of the road. Sections of the road, passing noise-sensitive areas, could be placed under the terrain as far as possible, while sections passing less noise-sensitive areas could be placed on or over the terrain. Placing a road in a cut might raise questions concerning groundwater level, flooding in extreme rain periods, etc. which should also be handled in the planning process. Handling of surplus rock material and spoil could also be an issue, but such material could also be used for earth walls for further noise abatement.


HELSINGØR
HELSINGE
Espergærde
Fredensborg
FREDERIKSVÆRK
HILLERØD
Nivå
Helsingør-
motorvejen
Lillerød
Jægerspris
Slangerup
Birkerød
E47
E55
Hillerød-
motorvejen
FREDERIKSSUND
FARUM
Ølstykke
KGS. LYNGBY
Værløse
Ganløse
STENLØSE
Jyllinge
BALLERUP
Frederikssund-
motorvejen
KØBENHAVN
GLOSTRUP
TAASTRUP
ROSKILDE
Hedehusene
E20
Holbæk-
motorvejen
Ishøj
Lejre
Tune
Greve
Køge Bugt
Motorvejen
Havdrup
Solrød
E20
E47
E55
Vest-
motorvejen
Syd-
motorvejen
KØGE
E20

Figure 4.4: As part of the strategic analysis of the long-term design of road capacity in Greater Copenhagen, the DRD carried out pre-feasibility studies of three different corridors, west of Copenhagen (black, blue and red lines).[52]

4.2 Environmental Impact Assessment

EIA is a tool used to integrate environmental concerns into decision-making processes. Council Directive 85/337/EEC [1], as amended, requires the assessment of the environmental effects of those public and private projects which are likely to have significant effects on the environment. The aim of an EIA is to provide environmental protection by foreseeing environmental problems and avoiding them. Another aim is to ensure that the public is given early and effective opportunities to participate in the decision-making procedures. Most countries in Europe either have regulations or guidelines describing how to perform environmental noise impact assessments [9].

A new version of the EIA Directive (2014/52/EU) [5] entered into force on 15th May 2014. This must be implemented in Member States by 16th May 2017.

The general objective of the new EIA Directive is to simplify the rules for assessing the potential effects of projects on the environment. This is in line with the drive for smarter regulation to reduce the administrative burden. It also improves the level of environmental protection, with a view to making business decisions on public and private investments more robust, predictable and sustainable in the longer term.

The new approach pays greater attention to threats and challenges which have emerged since the original rules came into force some 25 years ago. This means that more attention is paid to areas such as resource efficiency, climate change and disaster prevention, which are now more appropriately considered in the assessment process.

With the revised directive, certain environmental factors to be taken into consideration in the EIA process are reformulated. For example, the assessment of the exposure of the population is now formulated as ‘population and human health’ rather than ‘people’. In addition, environmental factors such as ‘biodiversity’ and ‘vulnerability to risks of major accidents and/or disasters’ have been added. The preamble to the directive specifies that new environmental challenges should be taken into account, e.g. good land use, sustainable use of soil and land, biodiversity, climate change and cultural heritage. It thus exhibits a broader focus on the environment, which must be taken into account when a project’s significant impact is assessed.

The new directive also focusses on improvements in public participation. EIA reports are to be made more understandable for the public, especially assessments of the current state of the environment and alternatives to the proposal in question. The new directive specifies that the timeframe for consulting the public on the EIA report should not be shorter than 30 days. Information regarding public participation procedures, etc. can be found in Chapter 8.

It is unclear whether or not the revised directive will have consequences in relation to the description and assessment of the noise impact of road projects. However, the trend of the revised directive seems to suggest that the requirements for EIA reports and the EIA process are shifting towards the following:

- Improved and more comprehensible description of the noise impact of projects;
- More focus on the human and health impact of noise from road projects;
- Facilitation of public participation, including through the provision of improved and more understandable information regarding noise impacts; and
- Improved focus on noise from the road construction process.

In this context, topics covered in Chapter 3 of this guidance book, such as assessments of cumulative noise, calculating total annoyance, ideas for better descriptions of noise impacts and methods for the assessment of noise impact on recreational activities, are all ideas which may contribute to meeting future EIA requirements. In addition, the relevance of Chapter 7 on construction noise and Chapter 8 on public participation will increase in relation to the new EIA Directive.

Noise impact assessment as part of an EIA is of great importance for the future environment in the vicinity of the road system. Such assessment is the basis for decisions on the implementation of necessary measures to minimise and avoid adverse impacts on health and quality of life due to future road noise. At the same time, there must be some kind of proportionality between invested funds and the effect of noise-reduction measures in the project.

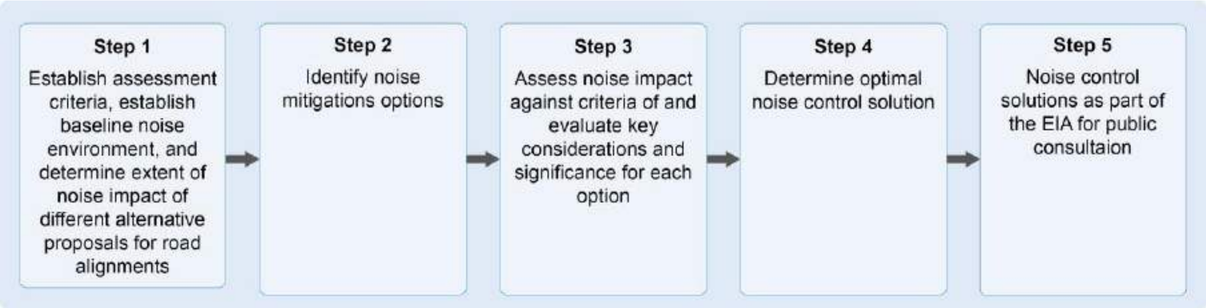

Figure 4.5: Simplified diagram of steps in noise impact assessments in an EIA, inspired by 'Guidelines for community noise impact assessment and Mitigation', I-INCE [53].

4.2.1 Establishing assessment criteria and a baseline study (step 1)

4.2.1.1 Noise limits and criteria for noise abatement

The road authority may have specific guidelines or criteria for determining when noise abatement is required. Otherwise, it is important to establish assessment criteria for the project or determine whether there are defined limits or scope for variation, based on the views of the community (refer to Section 3.2). This variation could be in either direction, i.e. making the limits more or less stringent.

Criteria for noise abatement vary from country to country and possibly from project to project. Generally, national legislation does not define any legally binding noise limit values for road noise (refer to [9] and [10] for more information on national noise criteria in Europe). Some countries have limit values that are usually followed when new urban or road development projects are developed and constructed, whereas guidelines are used in relation to existing housing and roads/highways (refer to Section 3.2). In many cases, the noise guideline limit value is approximately 55–60dB L_{den} outside dwellings; some countries also have guideline values for indoor noise.

The road noise design goal for new roads in Ireland, for example, is 60dB L_{den}. This goal, along with a set of other road-building requirements, is found in 'Guidelines for the Treatment of Noise and Vibration in National Road Schemes" [51]. The design goals determine whether mitigation measures are required. When the following three conditions are satisfied, noise mitigation is to be implemented (similar criteria apply, e.g. in Germany):

1. Combined expected maximum traffic noise level (from the new road and other traffic) in the vicinity is greater than the design goal;
2. Noise level at least 1dB more than the expected level without the planned road in place; and
3. The increase in noise level from the new road is at least 1dB.

4.2.1.2 Prediction horizon

In planning situations employing EIA, the noise is predicted using the national noise prediction method (refer to Section 3.3). A planning horizon has to be defined in relation to the traffic volumes included in the predictions. The majority of countries apply a prediction horizon of 10–30 years, and the most common planning horizon is 20 years [10]. If a country operates with a prediction horizon of 15 years, for example, it means that for a road opening in 2020, the design goal is to be applied for this year and for 2035 (referred to as the design year).

Other prediction horizons may also be used. The longer the prediction horizon employed, the more the noise consequences for the future development of the traffic volume can be taken into consideration 'up front', thereby enhancing the 'robustness of specific noise projects' [10].

In conjunction with this planning, and often legal, requirement to consider the most likely scenario for the design year, the more pessimistic 'worst-case' scenario may also be considered to prevent future noise impacts. Several factors which cannot be confidently anticipated can be taken into account by this (refer to Section 5.3.1).

When a road is planned, for example, to avoid noise levels above 60dB L_{den}, an increase of just 1dB in emissions could lead to new noise conflicts. However, by considering at an early stage in the planning process a lower limit of, for example 57dB i,e, a reduction of 3dB, a less impactful road alignment may be selected. Nevertheless, a 'design goal' of 57dB must not necessarily lead to additional noise protection to achieve this lower noise limit.

Figure 4.6 illustrates an exemplary situation; predictions indicate no conflicts in relation to a 60dB noise limit (yellow) for an alignment of the road (blue). With a rise of 3dB above the predicted value (e.g. due to a higher traffic volume), the noise limit is exceeded for the northern buildings (orange). A different alignment of the road with a noise limit of 57dB(A) can be found (lower row, purple line, previous alignment dotted blue). The southern receivers now have a higher noise load, but all receivers meet the limit of 57dB(A). With a rise of 3dB above the prediction, it is still the case that no receiver has a noise level above the noise limit of 60dB(A).

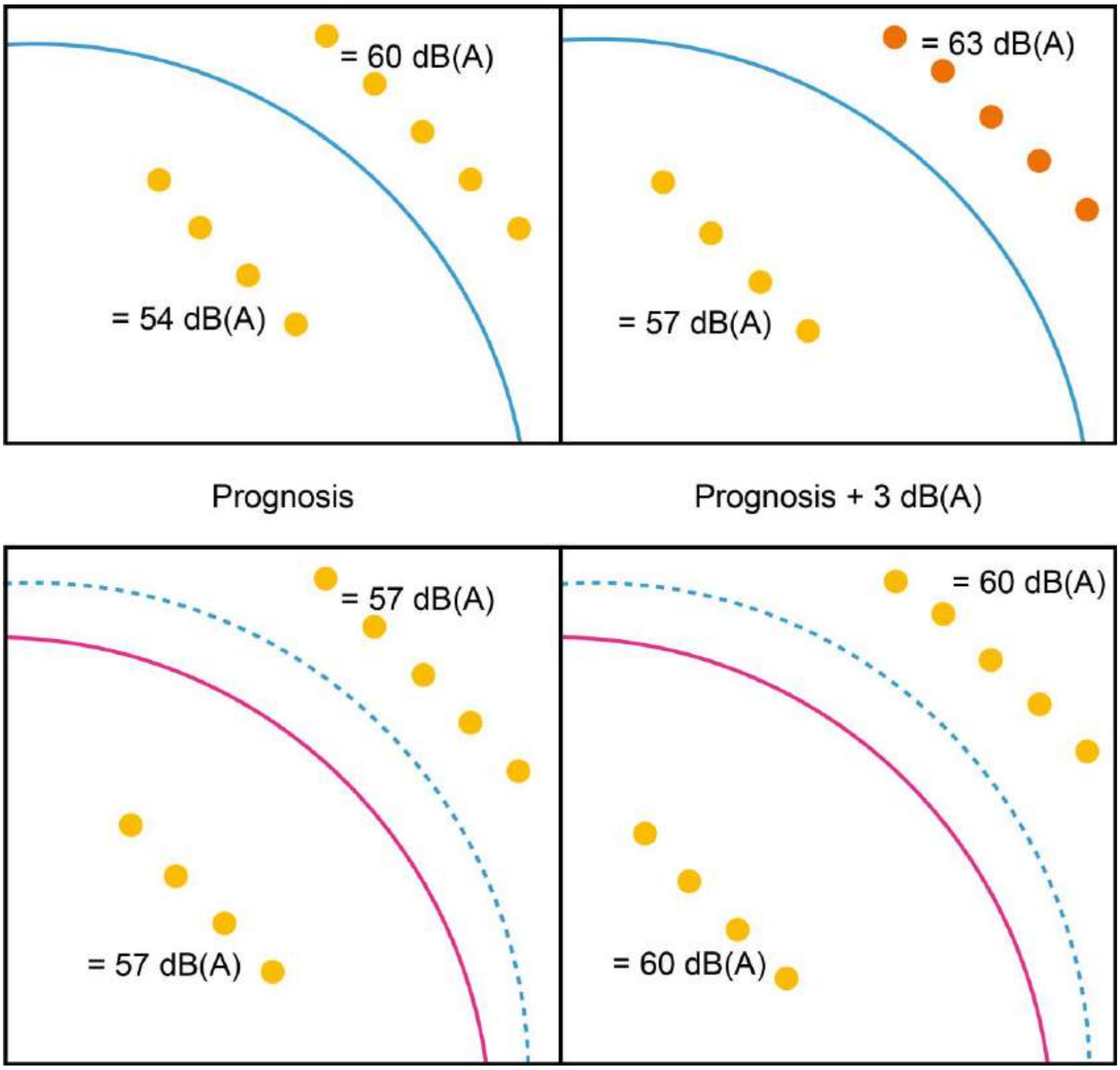

Figure 4.6: Sketch of changes to a road alignment, using a lower noise limit as a threshold.

4.2.1.3 Baseline noise levels

Baseline noise refers to the noise environment in an area which may be affected by the proposed road project. Such noise levels are normally predicted using the relevant national prediction method (refer to Section 3.3). Baseline noise levels can serve several purposes in the assessment process. They provide information on the current noise climate which may form the basis or justification for the applicable criteria. The potential for impact from a proposed road alignment is related to the noise the proposal will cause at a given location. The distance over which noise from the proposed road alignment could have an influence must be determined before the boundaries of the area for study are defined.

Once the area of potential concern has been established, the noise impact from the proposal at that stage can be predicted. Quantifying the noise output, especially at such an early stage in the project, is not a simple matter and is subject to uncertainty. Commercial software with different national noise prediction models is available to assist with such prediction (refer to Section 3.3).

The baseline levels, predicted levels and selected criteria should enable a breakdown of where there is an exceedance or otherwise of applicable noise criteria.

4.2.2 Identifying noise mitigation options (step 2)

At this step, options for noise mitigation measures are analysed and listed. Possible noise mitigation measures are described. The general strategy for noise control along major roads considers the following:

- Adjustment of the road alignment: This could include (if possible at this stage) adjustment of the road alignment so that the distance between the road and noise-sensitive areas increases or placing sections of the road passing noise-sensitive areas in cuttings (refer to Section 4.2.1.2);
- Reduction of noise at the source: This could include noise-reducing asphalt or traffic-related measures, for example, speed reduction (refer to Section 3.7.1);
- Reduction of noise between the source and the receiver: This could include noise barriers along the road or relocation so that shielding from buildings and other structures reduces the noise impact (refer to Section 3.7.2). It could also involve purpose-built barriers around the source or on the site boundary. Locating site access roads and entrances away from residential areas should also be considered; and
- Reduction of the noise at the receiver: This could involve proposals to construct local barriers at the receiver; it could also involve soundproof windows or façade insulation in the walls and roofs of buildings exposed to excessive noise impact (refer to Section 3.7.3).

4.2.3 Assessing the noise impact and determining a noise control solution (step 3)

This step can be an iterative process where different noise mitigation measures are in play. ‘What if’ scenarios can be investigated to clarify what is required to meet the noise criteria. It may not be the most effective acoustical solution which is the best compromise solution overall. For example, it is useful to assess the cost of noise mitigation measures in relation to the noise-reducing effect (cost effectiveness; refer to Annex A).

In connection with the EIA for the expansion of Motorway M3 in Copenhagen, cost-effectiveness analysis was carried out to determine the heights of noise barriers. Motorway M3 in Copenhagen has been widened from four to six lanes on 17km [54]. It is an urban highway, passing through densely populated residential areas. Before the widening, there were 1.5–2.0m high noise barriers along the motorway. As a part of the widening, almost 18km of 4m high noise barriers were constructed as well as noise-reducing road pavements and façade insulation.

Before the decision on the height of the noise barrier was made, calculations of the cost effectiveness of different heights of noise barriers were performed (3m, 4m and 5m), as presented in Table 4.2. As expected, the highest noise barrier (5m) brings the most noise reduction to the dwellings and hence has the lowest NEF (calculated noise annoyance, refer to Section 3.4.1 or Annex B for further information). The price of such a barrier needs to be taken into account to establish which solution is most appropriate. A 5m high barrier requires a stronger foundation, compared to barriers with a height of 3 or 4m.

The overall construction costs of the three types of barrier and their respective NEF reductions are presented in Table 4.3. From this study, it can be concluded that a 4m high barrier provides the best 'value for money' in terms of noise reduction. A similar study can be carried out with pavements offering different degrees of noise reduction, different earth mound heights, etc.

Table 4.2: Number of dwellings exposed to noise and NEF for different noise barrier heights [54].

Scenario	Number of Noise-exposed Dwellings					NEF
	55–60dB	60–65dB	65–70dB	>70dB	Total	
Baseline	6,503	3,244	482	76	10,305	1,717
3m barrier	5,472	2,985	526	78	9,061	1,568
4m barrier	4,766	1,890	253	36	6,945	1,087
5m barrier	4,027	1,663	238	35	5,963	948

Table 4.3: Evaluation of the price and cost effectiveness of the different barrier solutions [54].

Scenario	Total Price (Mil €)	Reduced NEF	Reduced NEF per 1 Mil. €
3m barrier	18.5	149	8.1
4m barrier	22.7	630	27.8
5m barrier	28.5	769	27.0

4.2.4 Comparisons between the noise impact from various road solutions (steps 4 and 5)

The aim of an EIA is to provide environmental protection by foreseeing and avoiding environmental issues. Moreover, it aims to ensure that the public is given early and effective opportunities to participate in decision-making procedures.

A noise impact assessment must describe the noise levels, the consequence (effect) of the change in noise level to the receptor and the significance of the noise levels and changes. The results of a noise impact assessment are typically noise maps illustrating noise propagation in the baseline study and various project proposals and counts of dwellings exposed to noise at different noise levels. In addition, several countries calculate the overall noise nuisance.

Further details on noise impact assessment are described in Section 3.1. Information regarding how to organise and handle public participation can be found in Chapter 8.

4.2.5 Example planning a new highway

This example demonstrates how noise was handled in the EIA, conducted as part of the planning of a new highway in Denmark [55].

The first step is to predict the future noise of the existing road network, taking an increase of traffic into consideration. In this instance, the future scenario represents the opening year of the forthcoming road project; however, another year may also be used to take increasing traffic over a longer planning horizon into consideration. The existing road network includes the existing major road, carrying the main traffic, as well as other minor roads which may have an influence on the overall noise exposure in the area.

This predicted situation is called the 'reference situation'. Alternatives to this reference situation are investigated in the EIA. They offer different alignments of the road and therefore various noise impacts on the surroundings. They are referred to as the main solution (the solution which is suggested as the best solution), alternative 1, 2, 3, etc. Noise mapping is conducted for these alternatives. The number of dwellings exposed to different noise levels is counted, based on the noise mapping, and the total noise annoyance is calculated based on the NEF for each dwelling (refer to Annex B).

An example of this kind is the EIA for a new road link over Roskilde Fjord. The purpose of the project is to improve the road capacity and connections over the fjord. The existing road passes through the city of Frederikssund.

Several alternative solutions have been studied in the EIA, as follows (refer to Figure 4.7):

- The N-solutions (N1 and N2) cover an enlargement of the existing road through Frederikssund, including noise barriers, etc.; and
- The S-solutions (S1, S2, S3 and S6) cover a new road link, south of Frederikssund (refer to Figure 4.7).

Figure 4.8 illustrates the grid noise maps for solution N1 and S1 (Main Alternative).

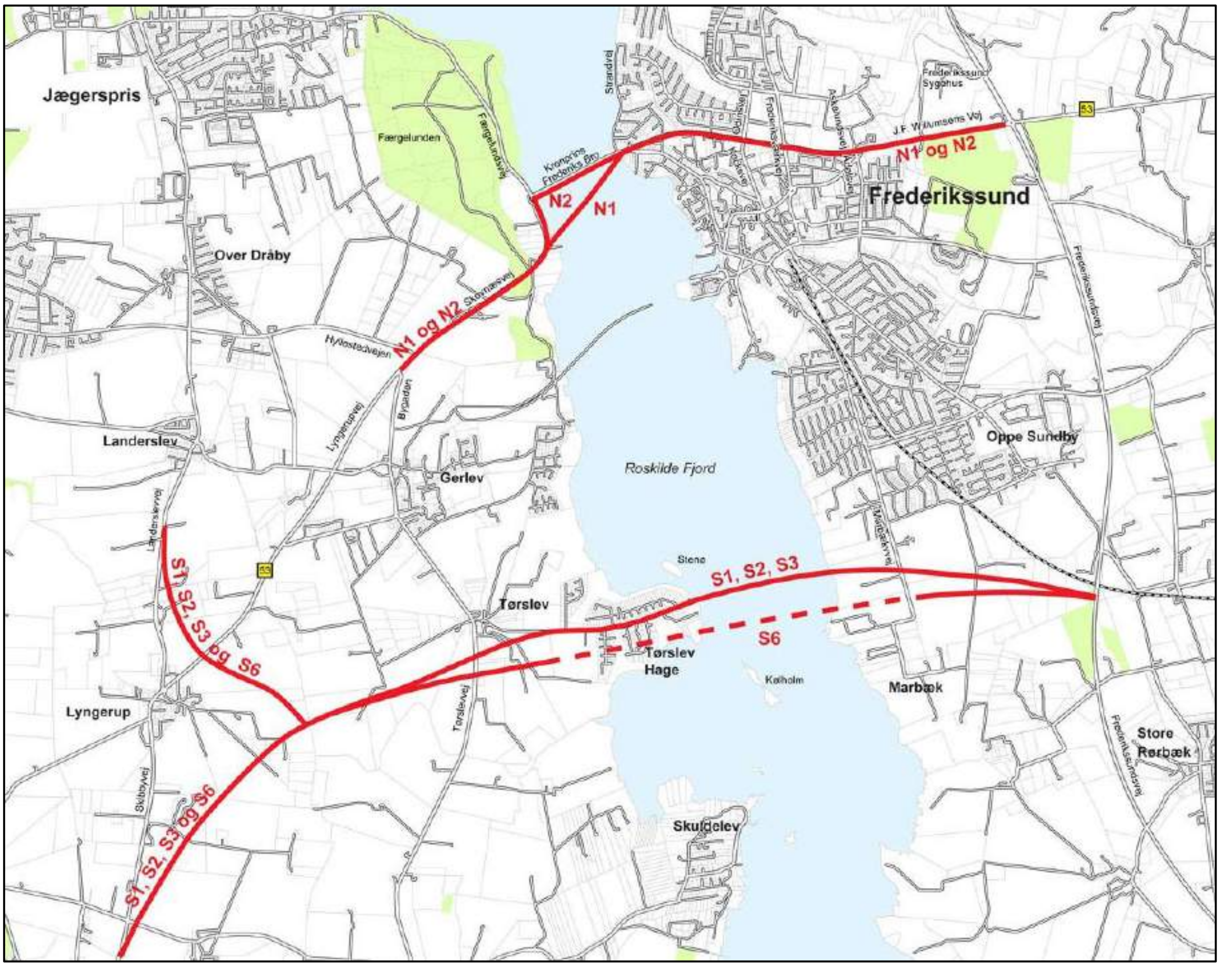

Figure 4.7: Northern and southern solutions for a new road link over Roskilde Fjord [55].

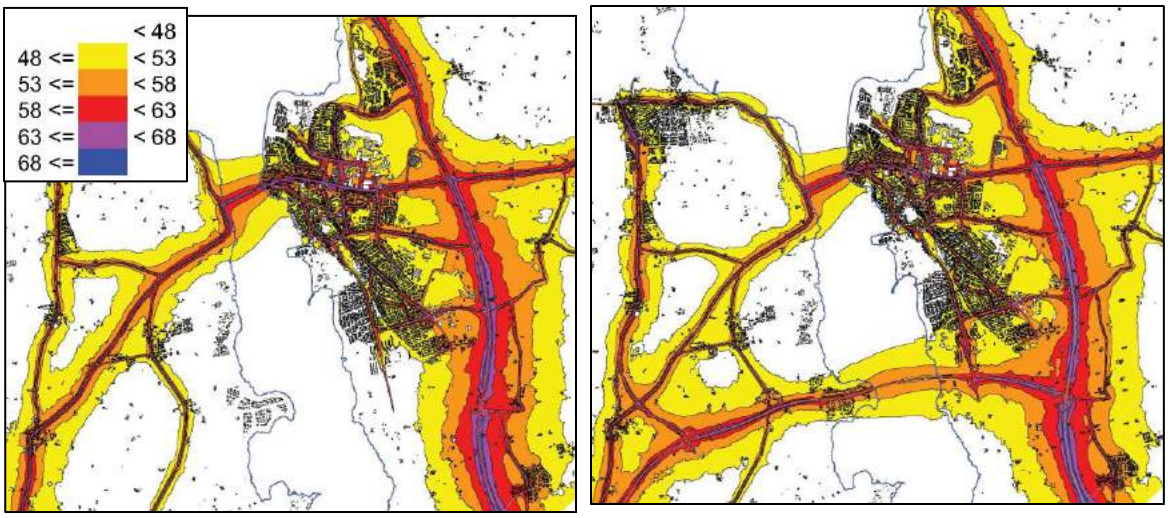

Figure 4.8: Noise maps illustrating the noise impact (L_{den}) of two different solutions – Alternative N1 (left) and the Main Alternative (right) with a new bridge, south of the city [55].

Table 4.4: Number of dwellings exposed to noise and the NEF for each solution [55].

Situation	Number of Noise-exposed Dwellings		NEF
	>58dB	>68dB	
Reference situation	1,817	93	281
N1, enlargement	1,780	79	271
N2, enlargement	1,785	76	267
S1, bridge (Main Alternative)	1,780	67	269
S2, short tunnel	1,766	67	268
S3, long tunnel	1,763	67	268
S6, very long drilled tunnel	1,762	67	268

In the reference situation, 1,817 dwellings in the area of investigation are exposed to more than 58dB (L_{den}). This represents an NEF value of 281. For the S1 solution (Main Alternative), this is reduced to 1,780 dwellings, with a reduction in the NEF of 12. The other alternatives represent similar reductions in NEF. This indicates that the alternative solutions offer less noise exposure for the dwellings in the area of investigation, mainly because the noise-exposed dwellings in town have obtained a reduction in noise. The NEF is included in the economic analyses of the road project. Generally, the socioeconomic benefits/costs due to reduced/increased noise from a new road project will not have a large impact on the overall impact estimates. The key consideration in the socioeconomic calculation is the travel time saved for the road users.

Counting dwellings and calculating the total noise nuisance (NEF) as an expression of road noise impact on the surrounding environment can be supplemented by further analysis and descriptions of the noise impact magnitude (refer to the following sections).

4.3 Detailed planning of road projects

This section describes how noise can be taken into consideration during the detailed planning phase, as well as in the design and engineering phase of a new road project or in a project where the objective is to enlarge or rebuild existing road infrastructure. Noise is just one of many concerns which have to be taken into consideration at the stage of detailed planning. Generally, factors such as landscape and geography, land use, flora and fauna, existing roads and intersections, materials to be imported and exported, groundwater level, risk of flooding during extreme rain, etc. will also form a framework in which noise has to be included. This section will, as will the rest of the guidance book, take noise as a main focus in the detailed planning process.

At this stage of the planning process, it will normally be necessary to perform detailed noise predictions of different alternative solutions in order to quantify the noise levels around the new road and evaluate the effect of different measures of noise abatement. This can often be a stepwise process where various solutions are investigated and optimised in relation to the noise-reducing effect. The national noise prediction method and relevant software packages can be used for this (refer to Section 3.3). Three-dimensional models of the terrain, receiver points such as houses and the alignment of the road are the input for the predictions of noise at this detailed level of planning.

In this phase, it may be relevant in some cases to establish a close cooperation between the design and engineering team and a specialist in performing advanced noise predictions.

4.3.1 Guidelines and limit values for noise

At this stage of the planning process, it may be relevant to start by listing the noise criteria that have to be taken into consideration in the actual project (refer to Section 3.2). This can either entail limit values for noise that must not be exceeded or guidelines that are optional to follow but that may secure a final project which results in an improved urban environment and living conditions surrounding the new road, if followed to some extent. By having noise high on the agenda in the planning process, it will sometimes be possible to choose solutions which can reduce noise without resulting in high extra costs to the total road project. This could be called intelligent and cost-effective noise abatement management.

Depending on the actual land use of the areas adjacent to a new or enlarged road, guidelines and limit values for noise could apply to one or more of the listed types of land use, as follows:

1. Residential areas;
2. Areas used for offices and business;
3. Urban areas with institutions such as kindergartens, schools, hospitals, etc.;
4. Areas with summerhouses and other tourist facilities such as hotels and campgrounds;
5. Recreational areas, parks and allotment gardens; and
6. Rural areas that are defined as special silent areas.

The areas for noise considerations that are relevant in a specific road project will depend on the actual geography and land use and planned future changes in land use.

Limit values and guidelines will often be defined and fixed in earlier stages of the project, e.g. in the EIA procedure, in the parliament’s or another legal institution’s (regional or municipal council) decision on the road project or in general national guidelines for noise.

If limit values and guidelines for noise have not been defined previously in the planning process, it can be suggested that this be done at this stage of the project where detailed planning is performed. In this way, the planning project will identify some goals and guidelines for noise which have to be integrated into the process of planning the road project. This can ensure that noise will be kept on the agenda throughout the working process of the design and engineering phase. There may be approval procedures to follow in a given project when defining criteria for noise at this stage of the planning.

The outcome could be that there will be one or two types of noise criteria for a road project, as follows:

1. Limit values for noise which have to be followed: These could be noise levels at the façade of existing residential buildings which must not be exceeded. In this case, the objective will be to find the optimal solutions where the noise criteria can be fulfilled in the most cost-effective way, taking into consideration other restrictions and requirements which also have to be fulfilled in the given project; and
2. Guidelines for noise which do not have to be followed but that if generally followed would improve the environmental quality of urban and green areas, as well as rural areas: In this case, the objective will be to investigate whether solutions can be found that can reduce noise with no or only marginal costs to the project. Restrictions and requirements which have to be fulfilled in the given project must be evaluated and taken into consideration.

Generally, noise limits and guidelines are not at a zero-effect level (refer to Sections 3.1 and 3.2). Therefore, noise complaints can be expected from the neighbours of a newly constructed road even though the limits and guidelines for noise are followed in the design phase.

4.3.2 Choice of pavement

The use of noise-reducing pavements is often the most cost-effective tool in noise abatement; however, such pavements may be more expensive than ordinary pavements and often have a shorter lifecycle (refer to Section 3.7.1). The surface texture of such pavements is optimised to reduce the generation of tyre–road noise and possibly absorb noise to a certain degree [27].

These pavements are often more cost effective than noise barriers. Noise-reducing pavements decrease the noise from the source, and thereby generally reduce the noise around the corridor of a new or enlarged road. However, there are limits to how much noise-reducing pavements can reduce the noise; therefore, it may be necessary to use a combination of different tools for noise abatement.

In some of the national noise predictions methods, there are reduction factors for the noise-reducing pavement types, typically used in the given country (refer to Section 3.3). Use of these factors must be recommended when performing predictions of the effect of using noise-reducing pavements.

It may be beneficial to consider noise-reducing pavements as the first tool for noise abatement after investigating the possibility of using increased distance and possibly placing the road in a trench (refer to Section 3.7). The decision to use noise-reducing pavements may already be included in the project's EIA procedure.

If profiled road stripes are planned for traffic safety reasons, this might create extra noise when vehicles are driving on these stripes. Only a few passes by heavy vehicles at night can result in complaints from residents. It is generally recommended to use types of road stripes that generate as little extra noise as possible. Profiled stripes are therefore unsuitable at road sections along residential buildings. The extra noise from such stripes is normally not taken into consideration in noise predictions.

4.3.3 The final decision on road alignment

Generally, the alignment of a new road through the landscape and urban areas is determined during the EIA procedure and planning. At the stage of detailed planning, there will only be limited freedom to make small adjustments to the alignment of the road. When choosing the final alignment, noise can be taken into consideration by evaluating if it could be possible to increase the distance to residential buildings or other noise-sensitive areas. If possible, the distance from noise-sensitive areas to intersections, flyovers and connection lanes/ramps to crossing roads should be made as wide as possible.

Figure 4.9: A new highway in Denmark constructed in a ditch with an earth wall at the side. The sides of the ditch, which include vegetation, are noise absorbing.

For reconstruction and enlargement projects of existing roads, the alignment of the road is fixed. However, the question of whether the road should be enlarged on the right or left side can be raised. Noise may be reduced by enlarging on the side giving the largest distance to residential buildings. New or rebuilt intersections can be placed with distances from buildings which are as large as possible.

A new road can be placed on an embankment, on the level of the terrain or in a trench. Many factors can influence which solution to select. From the point of view of noise, placing the road on an embankment normally increases the noise because the sound-absorbing effect of the ground surface between the road and noise-sensitive areas will be reduced. From a noise point of view, placing the road on ground level can be considered the neutral solution.

Placing the new road in a trench will reduce the noise, as the sides of the trench will function as a noise-reducing earth bank. The deeper the trench, the more the noise will typically be reduced. If using a trench solution, a lot of surplus material will be generated. If this material can be placed as an earth bank along the road, it will improve the noise reduction (refer to Figure 4.9). However, such a solution will require use of extra land along the road for the sides of the trench, as well as for the earth banks.

If the sides of a ditch are constructed with an angle, and vegetation such as grass and bushes are grown on the side of the trench, this area will absorb noise rather than reflecting it to the sides of the road. In order to save land, the sides of the ditch can be constructed as vertical concrete walls. Such hard walls will reflect noise to the sides of the road. In this instance, it must be evaluated whether it is necessary to mount noise-absorbing elements on the concrete wall to reduce the reflected noise.

In urban areas, the choice of a trench with concrete sides can be supplemented with noise barriers, as illustrated in Figure 4.10.

Figure 4.10: Highway through a densely populated area in Barcelona, Spain, constructed in a ditch with concrete sides and noise barriers bending over the road.

Figure 4.11: The ramp of a highway intersection, constructed as a 'flyunder' to reduce noise exposure to neighbouring residential and public green areas.

At highway intersections, ramps are often constructed on bridges that can be quite high. This will normally increase the noise propagating to the surroundings. If there is a need for noise abatement, it can be considered whether the ramp can alternatively be constructed in a trench or tunnel (refer to Figure 4.11).

If there is a surplus of spoil or rock material at a section of a new road, it can be used for landscape modelling that which create earth banks, thereby providing noise protection. Surplus materials from other local construction projects can possibly be used in the road project to improve landscaping and noise abatement assuming compliance with relevant waste management legislation. Contacts with municipal building and environmental administrations may provide valuable information and raise possibilities. The road project may be able to integrate the plan for local extra materials to be placed over a period of 20 years, for example, on some sections of the road, giving extra noise reduction to target locations such as recreational areas. This might be an approach to meeting the guideline for noise protection of a public green area over a longer period. The road project could reserve the relevant land area for this and design the plan for the earth barrier; the municipality could perform and administer the work of constructing the earth barrier through the following years after the road has been constructed.

At this stage of planning, it can also be relevant to consider the noise from the road construction process. Some sites of the construction will be especially noisy and/or have a long duration of noise exposure. This could involve sites with large earth works or rock removal, construction of bridges and flyovers, hammering or vibrating of steel plates, etc. If it is possible to locate such construction sites a far distance from residential areas, this will help the residents and also secure a lower cost for noise abatement during the construction process. Chapter 6 describes how noise can be managed in the road construction process.

4.3.4 Noise barriers, earth banks, etc.

Noise barriers may be needed along sections of a new or rebuilt road in order to fulfil limit values for noise. Without a noise barrier, the noise generated by the road traffic propagates freely from the source to the receiver (refer to Section 3.7.2).

The following simple rules of thumb from Section 3.7.2 can be used in the first phases of planning noise barriers and earth walls:

- The noise barrier should be placed either as close to the road or residential buildings as possible or other areas which have to be protected;
- Increasing the height of a barrier, increases the noise-reducing effect; and
- At a given point location or building in the terrain, the noise which affects this point location comes from all the sections of road that can be ‘seen’ from this point location. To optimise the effect of noise barriers and earth walls, it is necessary to cover all or most of the road sections which can be seen i.e. block the line-of-sight. Therefore, if a barrier can reduce the noise at a residential area along the road, it must be longer than the length of the residential area.

It is recommended to use the national prediction method to perform a series of noise calculations in a 3D environment to find the most cost-effective solutions (placing of barrier, length and height, etc.). The DRD has produced a simple noise viewer which may be used in some cases as a first tool to evaluate possible solutions (refer to [56]). Some general rules for the effect of a noise barrier were presented in Section 3.7.2, as follows:

- The noise is reduced by 2dB every time the height of the barrier is increased by 1m, until a total height of 4m; and
- The noise is reduced by 1dB every time the height of the barrier is increased by 1m, over a total height of 4m.

Furthermore, consideration should be given to the sound absorption/reflection of the noise barrier. Generally, absorbing barriers are more expensive than reflecting ones. If earth walls are used, they absorb ‘naturally’. Tilting barriers approximately 7 degrees backwards will direct the reflected noise higher in the air, so that it may not affect noise-sensitive areas along the road. This solution is used in noise barrier projects in the Netherlands. Frequently, barriers with integrated green vegetation or with vegetation in front of the barrier also work as absorbing barriers.

Using barriers at the sides of a highway and applying barriers in the middle of the road can be considered, as such barriers may enhance the noise reduction.

Partly covering the road for noise-abatement purposes can be a necessary solution if the road passes close to residential buildings with many stories (refer to Figures 4.2 and Figure 4.10).

Total covering may need to be considered, but this is an expensive solution (refer to Figure 4.12). Generally, this will already have been determined during the EIA process. Total covering has the advantages that the noise is essentially fully mitigated. The ‘reclaimed’ area over the road can either be used for a green area, binding the town together, or for urban development with dwellings, offices and shops. By selling the land for such purposes, revenue is generated which can be used to pay for part of the construction cost of covering the road.

Figure 4.12: A new highway near the Copenhagen airport covered at a section of 700m where the highway passes some blocks of apartments. The areas over the highway have been used as a green area, binding the urban environment at the two sides of the highway together.

Good design is important for the road users, as well as for the residents and users of green areas at the side of the noise barrier, as they will have to view at the barrier daily. In some projects, an architect or landscape architect works with the road planning team when designing the visual layout of the road and noise-abatement solutions such as barriers. There are many technical solutions and designs of noise barriers (refer to the examples in Annex C).

Occasionally, special barrier designs are developed for a project; at other times, standard solutions are used.

Secondary functions in addition to noise abatement can be integrated into noise barriers and earth walls (refer to Section 3.7.2). Photovoltaic panels for the production of electricity could be integrated into noise barriers or placed on earth walls (refer to Figure 4.13). The revenue from selling the produced electricity can be used to finance or partly finance the construction of noise barriers and earth walls (refer to the example in Annex C).

Cooperation with residents in the selection phase of barrier design may be considered. This can provide people with ownership of the selected solution, and at the same time, the public consultation process can be used to ensure that people have realistic expectations of the noise levels after the project has been completed. In Chapter 8, procedures and methods for facilitating public participation are presented.

Figure 4.13: Noise barrier with vertical photovoltaic panels at the top (by permission of VicRoads, Melbourne, Australia).

4.3.5 *Noise abatement by the receiver*

In some situations, there are single residential buildings along a road in rural areas where it is not possible to reduce the noise sufficiently using source-related measures. In addition, it will often be very costly to build a noise barrier along a highway to protect just one or a few houses, as such a barrier normally will need to be very long in order to create sufficient noise reduction. If there is a need to reduce the noise at a single or a few noise-exposed buildings, the following solutions may be considered:

- Façade insulation;
- A local noise barrier around a terrace and/or sections of a garden;
- Buying the house and demolishing it; or
- Buying the house, rebuilding it with a less noise-sensitive purpose – such as for a factory or storage – and selling it again.

Depending on the building design and maintenance conditions, different types of noise insulation are necessary (refer Section 3.7.3). Figure 4.14 illustrates an example with the glass covering of balconies.

Generally, it will be a building acoustician, possibly from a consultant firm, who investigates what kind of insulation and improvement is needed and estimates the cost.

To create reasonable conditions in outdoor areas, the use of local noise barriers around a terrace, sections of a garden or similar may be considered (refer to Figure 4.15).

As part of the detailed planning of local noise barriers, façade insulation, etc., it is necessary to define procedures and responsibility for the ongoing maintenance of these devices and building elements.

Figure 4.14: Balconies covered by glass in order to reduce noise from a nearby highway, as the noise barrier did not provide sufficient noise reduction to fulfil noise limits.

Figure 4.15: A single house in Norway with local white wooden noise barrier around the terrace designed in the same style as the house (photo by permission from the Norwegian Road Administration).

4.3.6 Traffic-related measures for noise abatement

The background for constructing new highways is often the creation of new arterial roads of the primary road infrastructure system. The purpose of such construction is to create fast access for a large number of passengers and cargo. Therefore, establishing restrictions on traffic volume and/or speed is normally not the first 'natural' measure of noise abatement to consider. A new highway which passes close to larger residential areas can cause noise annoyance and sleep disturbance at night. In principle, the following measures of noise abatement may be considered (refer to Section 3.7.1):

- General speed reduction (refer to Figure 4.16);
- Speed reduction at night time (such as from 22:00 to 06:00)
- Speed reduction for heavy vehicles at night time (such as from 22:00 to 06:00)
- A ban on heavy vehicles at night time (such as from 22:00 to 06:00)

It must be noted that adding a sign with a reduced speed does not reduce the noise on its own. The noise is only reduced if the actual average speed of the traffic is reduced.

Figure 4.16: A speed reduction from 110 to 90km/h was part of a noise reduction project along 3km of Highway E4 passing a residential area near Husqvarna, Sweden, with a traffic volume of 22,000 vehicles per day. The sign at the roadside states 'Reduced speed because of noise' (refer to example in Annex C for more details).

5 Maintenance and monitoring of roads

The road authorities have a responsibility to maintain the road infrastructure, ensure that the roads and road-related equipment are in suitable condition and verify that the resources invested in the road infrastructure are preserved as well as possible. Noise is one of many parameters that can be taken into consideration in maintenance procedures. This chapter considers how road authorities can 'maintain' and even improve the noise environment in urban areas along the existing road network. The chapter is divided into three main parts, as follows:

1. Noise considerations in road maintenance and management (refer to Section 5.1);
2. Planning of noise abatement along the existing road network (refer to Section 5.2); and
3. Prevention of new noise conflicts (refer to Section 5.3).

5.1 Noise considerations in road maintenance and management

The three stages in the 'noise chain' (refer to Figure 3.10 in Section 3.7) can also be used as a framework for describing how noise may be taken into consideration in the ongoing road maintenance and management, as follows:

1. At the source, the focus will be on the pavement type when renewing pavements;
2. Under propagation, the focus will be on monitoring and maintaining noise barriers so that the noise-reducing effect is preserved and the barriers are correctly maintained and do not deteriorate;
3. At the receiver, the focus will be on the development of noise levels at the façade of buildings and in outdoor areas for private and public recreational use.

5.1.1 Noise source-related considerations – pavements

The most important source of noise from highways is tyre–road noise. For passenger cars and heavy vehicles, tyre–road noise is the dominant source at speeds over approximately 35km/h and 60km/h, respectively. The road engineers decide what type of pavement to apply when renewing worn, old pavements. This decision has a significant influence on noise from a given road or highway. It is therefore important to consider noise together with other relevant factors such as durability, lifetime, price, traffic safety, winter maintenance, etc. when deciding which pavement type to use.

The standard pavement type used varies from country to country in Europe. Generally, however, the most frequently used pavement types are dense AC or SMA. From an acoustic viewpoint, these pavements can be regarded as reference pavements. It is the national standard pavement type which is typically used as the reference pavement in the national noise prediction method (refer to Section 3.3). In Europe, there are different traditions and various pavement technologies applied.

Some pavement types, set out below, are noisier than reference pavements:

- Surface dressing or chip seal;
- Hot-rolled asphalt;
- Standard AC and SMA with a very large aggregate size;
- Cobblestones; and
- Concrete blocks.

Around Europe, the contracting industries develop, produce and market various types of noise-reducing pavements. There are many company products with different names. Some of these pavement types are as follows:

- Standard AC and SMA with a very small aggregate size;
- Thin open layers; and
- Porous asphalt with one or two layers.

The level of tyre–road noise depends on the surface texture of the pavement and other pavement surface–related factors (refer to Section 3.7.1.1).

Cement concrete pavements are generally considered quite noisy. However, the surface texture of such pavements can be optimised to achieve reduced noise levels [27].

The noise from all pavements increases over time. This increase depends on the pavement type and additional factors [27, 28] such traffic volume, meteorological conditions, etc. Figure 5.1 illustrates an example of the development over time of the noise from a standard SMA 11 pavement; in this case with an expected lifetime of 17 years and a noise-reducing thin layer with an expected lifetime of 12 years. The example covers a period of 51 years, equal to three lifecycles of the SMA 11. In this example, the average noise reduction for the noise-reducing thin layer is 2.2dB in relation to the SMA 11. For planning purposes, it is sensible to use the average noise levels, as well as the average noise reduction. Generally, such average noise reductions are built into national noise prediction methods which can take noise from different pavement types into consideration (refer to Section 3.3).

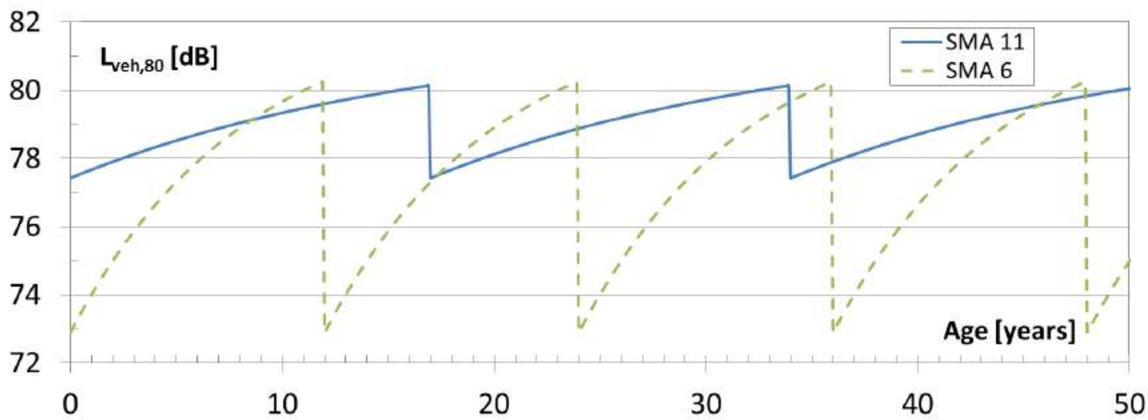

Figure 5.1: Constructed example of the development of noise over time for an SMA 11 standard pavement and a noise-reducing SMA 6 thin layer over a period of 51 years. The average noise level over the lifetime of the pavements is 2.2dB [43].

Road administrations can chose to have very detailed and precise information about the noise emission of the pavements on the road network. This information can be collected using CPX noise trailer measurements (refer to Figure 5.2). This is similar to measuring surface texture, friction, evenness, rutting, etc. as performed regularly by road administrations to get the up-to-date status regarding the conditions on the road network. Such CPX measurements can be performed yearly or at longer intervals such as 3 or 5 years. The measured noise data can be stored in the road databank used by the road administration.

Figure 5.2: Open (to the left) and closed (to the right) CPX trailers for noise measurements on roads.

If CPX measurements are performed, the results can be used to produce a map of the actual noise emissions on the road network every year or less frequently. Such a map differs from the noise map produced in relation to the END (refer to Section 7.1), which reflects average noise levels over long periods of time. A noise map based on CPX noise measurements will highlight road sections with pavements exhibiting high noise emissions. This information on noise emission can be used in the yearly process of deciding which road sections need the pavement renewed. In this way, noise can be one of the parameters normally used in the process of deciding which road sections to renew. For example, one strategy could be to give high priority to road sections passing residential areas and which have pavements with high noise emissions.

The DRD has developed a method for how noise can be taken into consideration as an active parameter in PMS [37] (refer to Section 3.4.4 for more information). The CEDR noise project QUESTIM [57] has also described procedures for this.

Beyond the noise emissions of a road, which are mainly derived from the condition and type of road surface, noise can be taken into account in relation to the noise impact of the road, for example, by considering the resulting number of people exposed to noise. Section 3.4 describes several methods for an evaluation of noise and noise abatement as well as for noise 'hotspot' identification which may also be used in the planning of pavement renewal.

New Dutch research indicates that rejuvenation with bitumen emulsion of thin noise-reducing pavements and porous pavements can occasionally extend the lifetime of such pavements [58, 59]. Rejuvenation may save money in the long term by increasing the lifetime of noise-reducing pavements, but the rejuvenation process has a cost which must be integrated in budgets for road maintenance.

Recommendations on pavement maintenance and noise are as follows:

- Using the least noisy pavement type that is sufficient at a given location. This is especially relevant where roads and highways pass noise-sensitive residential areas and recreational green areas;
- Giving priority to renewal of noisy pavements where roads pass noise-sensitive areas;
- Considering repair of potholes, ravelling and cracks, which can increases noise;
- Carrying out rejuvenation, which can increase the lifetime of noise-reducing pavements;
- Avoiding manholes and lids of any kind in wheel tracks, if possible, which can increase noise;
- Repairing loose and poorly maintained manholes and lids; and
- Using the quietest type of profiled road stripes and avoiding them at road sections near houses (including single houses). These are used for traffic safety purposes to warn drivers that they are about to leave the driving lane; they can increase noise and especially annoyance. At night time, this might cause sleep disturbance.

Figure 5.3: Noise can be used as an active parameter in the pavement maintenance process.

5.1.2 Noise under propagation – barriers

Noise barriers are constructed to reduce noise behind the barriers and are generally designed to provide a neutral or remarkable visual contribution to the urban and rural environment (refer to Section 3.7.2). Noise barriers represent a significant investment and are part of 'road capital', i.e. an asset. It is important that the acoustic and non-acoustic elements of the barriers are maintained to ensure the long term performance of the asset. A noise barrier can be regarded as a piece of road equipment similar to lamp posts, road signs, emergency telephones, grass verges, vegetation, water runoff systems, etc. The CEDR project QUESTIM [60] supplies information on integrating noise barriers in management of the quality of the road network.

Figure 5.4: At some locations, graffiti can be a problem which detracts from the visual appearance of noise barriers. Cleaning activities are needed in such situations.

Some noise barriers seem to attract 'graffiti artists' (refer to Figure 5.4). Graffiti often impairs the visual performance of a noise barrier, and will therefore require cleaning. Graffiti can be difficult to prevent. Therefore, the risk of graffiti should be taken into consideration in the process of selecting the barrier type and design. If the shape and surface structure of a barrier makes it difficult or impossible to paint on, graffiti may be avoided. The DRD has developed a no-graffiti barrier type with vertical wooden posts, placed close together (refer to example in Annex C). Generally, vegetation also reduces the risk of graffiti.

Holes and cracks in noise barriers reduce the acoustic effect (refer to Figure 5.5) and therefore need to be repaired.

Figure 5.5: Steel noise barrier damaged by snow removal equipment (left). The two open cracks reduce the acoustic effect. The opening between the steel post and concrete foundation (right) also reduces the acoustic effect.

Noise barriers can be constructed to have a noise-absorbing surface in order to avoid reflection of noise to the 'other side' of the road. This is often achieved using perforated steel plates with an absorbing material, such as mineral wool, behind them (refer to Figure 5.6). The absorbing material can disappear over time due to tear and wear. In such cases, the noise-absorbing performance of a barrier is reduced or lost; therefore, maintenance activities must be considered.

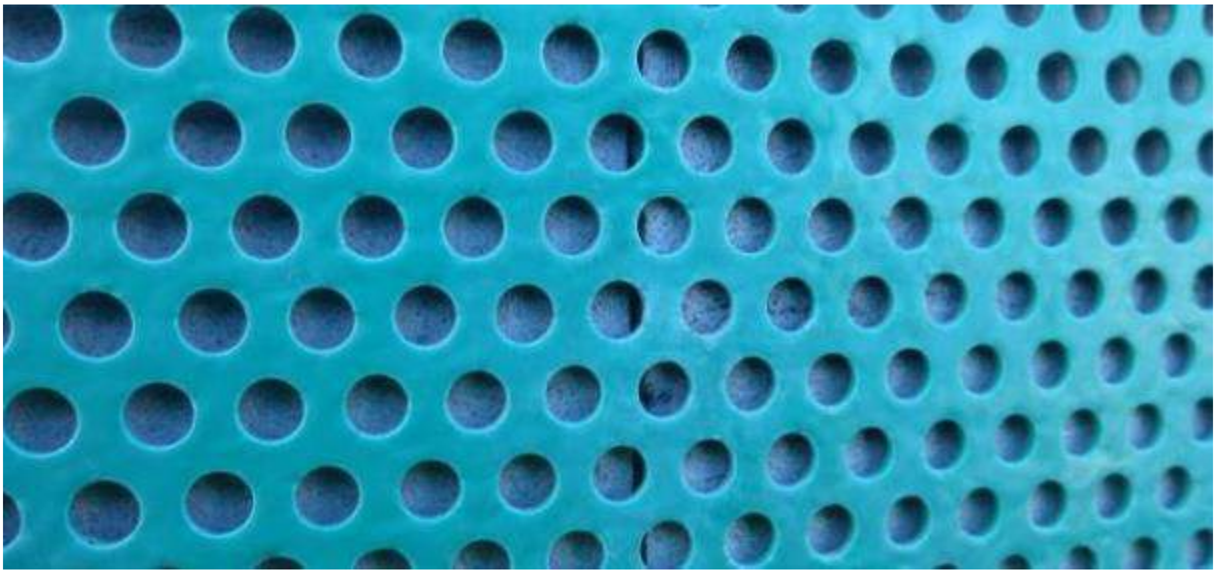

Figure 5.6: Close-up of a noise-absorbing barrier with perforated steel plates with absorbing material behind.

Generally, barriers and earth walls with vegetation will need some kind of maintenance (refer to Figure 5.7). The vegetation may need to be cut down, dead plants replaced, etc. If green vegetation is used in front of a barrier in order to reduce noise reflections, it is important to ensure that the vegetation in place there and in good condition as the years goes by.

Figure 5.7: Noise barriers with vegetation which may require maintenance.

There is an obvious requirement to establish ongoing monitoring of the condition of noise barriers. The procedures for inspecting and monitoring other road equipment could include inspection of the condition of noise barriers and earth walls. For noise barriers, such procedures should focus on the following questions:

- Is the structure of the barrier intact or are there damaged elements or broken transparent parts which need replacement?
- Is cleaning needed (this is especially relevant for transparent barriers and barriers with photovoltaic panels)?
- Are steel and wooden barriers in a condition or is painting/impregnation needed?
- Are there holes and cracks in the barrier which need to be repaired?
- Is the absorbing material intact (if relevant)?
- Have graffiti been painted on the barrier?

Such an inspection will need to be performed both at the road side, as well as on the residential side of noise barriers. In order to secure adequate long-time functionality of the noise barriers and to maintain the capital invested, such monitoring may have to be performed annually. Both monitoring noise barriers and maintenance activities have a cost which has to be included in relevant budgets.

Earth walls will often be 'self-maintaining' to a high degree, but they may occasionally require cutting of grass and bushes, and replanting.

5.1.3 Noise at the receiver – noise mapping follow-up, etc.

When considering noise impacts at receivers located near roads the focus can be on increasing noise levels experienced over time.

Noise mapping is a tool for monitoring changes in the levels of noise exposure at dwellings over time (refer to Figure 5.8). According to the END [14], which is implemented in national legislation and procedures, reviewed or revised noise mapping has to be performed every fifth year for all roads with a traffic volume of more than 8,200 vehicles per day (refer to Section 7.1). These five-year updates of noise maps provide the road administration with a tool whereby the development of noise exposure to the neighbours of the road network can be monitored.

By counting the number of dwellings exposed to different noise levels and generating statistics, tables can be set up indicating the development of noise over time. Table 5.1 provides a constructed example where there is a slight increase of the number of exposed dwellings over time caused by an ongoing increase in traffic volume. The noise maps also provide the background information for the noise action plans which are to be developed by the road administrations every five years (also in accordance with the EU END [14]; refer to Section 7.3).

Table 5.1: Development of the number of noise-exposed dwellings over time for a road network caused by traffic volume increase – a constructed example.

Noise as L_{den}	2007	2012	2017
55–59dB	3,000	3,200	3,300
60–64dB	1,000	1,050	1,080
65–69dB	500	520	530
70–74dB	100	104	110
Over 75dB	5	5	6
Total over 55dB	4,605	4,879	5,026

Generally, the purpose of noise mapping is to predict the average noise levels over time. Therefore, the average lifetime noise levels for different pavement types are used. As mentioned previously, these are the noise levels which are normally integrated into the national noise prediction methods (refer to Section 3.3). Noise mapping generally does not reflect the yearly increase of noise from different pavements due to age and wear and tear (refer to Section 5.1.1).

If a road administration wants a full analysis of the noise exposure of the neighbours along the road network, all of the roads passing residential areas can be included in the noise mapping and not only roads with a traffic volume of more than 8,200 vehicles per day. Noise mapping is a useful tool in the ongoing maintenance and management of the road network. Strategies for integrating noise as an important factor in the ongoing maintenance and management of roads can be developed and defined in noise action plans (refer to Section 7.3). It is important for the quality of the noise mapping that the background data used for the predictions are correct and updated. The road administration should ensure the following data is updated and controlled as appropriate prior to undertaking revised noise mapping:

1. Changes in traffic volume and percentage of heavy vehicles;
2. Changes in average speed caused by changes in speed limits, traffic regulation, implementation of an automatic and intelligent traffic control, etc.;
3. Construction of new noise barriers and earth banks;
4. Changes in the land use along roads; and
5. If pavements are changed to new types with other noise properties, this must be taken into consideration. This could be an application of noise reducing pavement types.

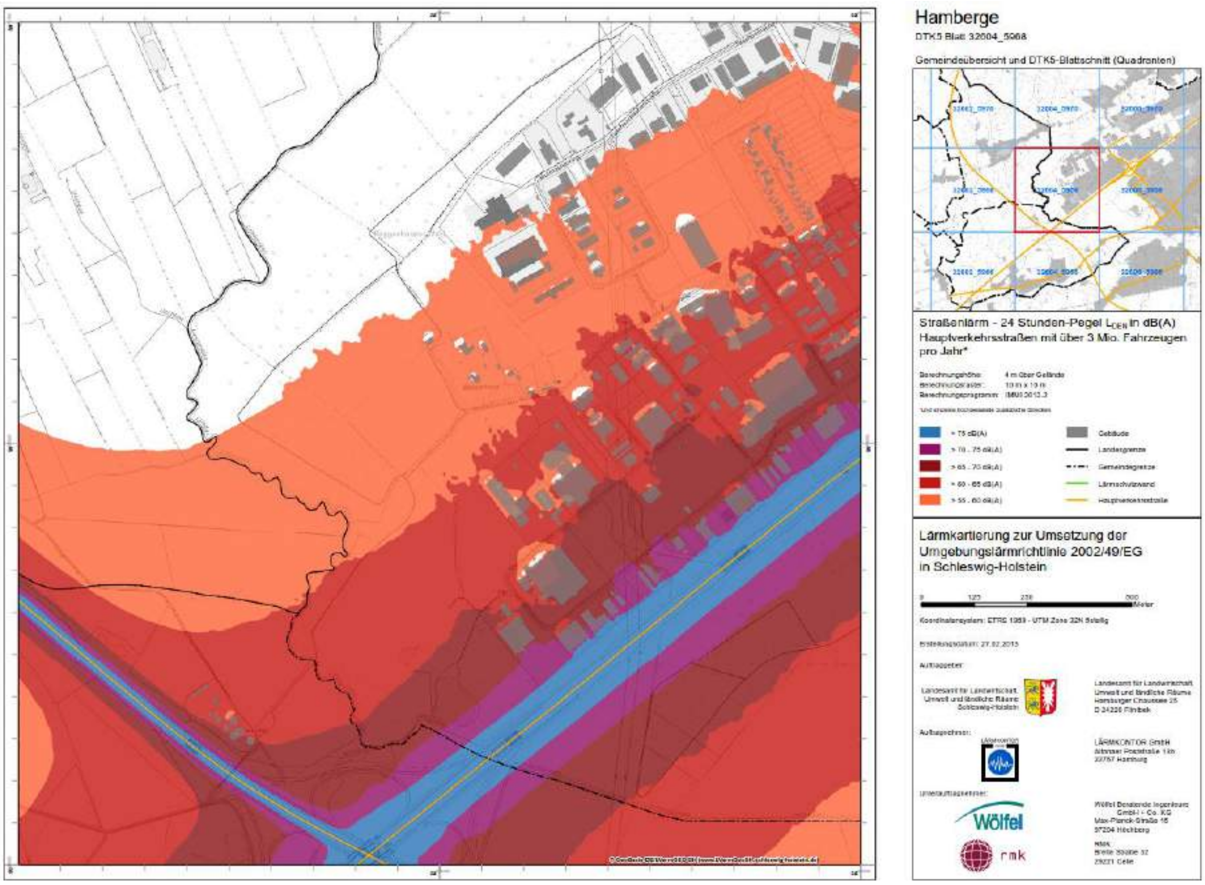

Figure 5.8: Noise maps along major highways have to be recalculated every fifth year.

A road administration could establish procedures so that ongoing changes in parameters that are important for the five-year noise mapping are systematically registered. For example, such information could be stored in the road database of the administration. In this way, noise maps will more accurately reflect the actual noise situation; it will also save time for producing noise maps if the relevant updated information is already available.

It is the obligation of the property owners and the residents to maintain residential buildings and outdoor areas. Generally, this is also the case in situations where noise-reducing windows and façade elements have been applied (refer to Section 5.3.2). Road administrations normally do not have a role in this. If a road administration has contributed to the planning and financing of noise reduction of dwellings and outdoor areas, the administration could produce information material on the appropriate maintenance of the noise-reducing elements (refer to Figure 5.9). This will aid in ensuring the correct maintenance of noise abatement products funded either publicly or privately. The road administration could also consider being proactive and engaging in dialogue with the relevant owners and residents to support the best possible maintenance of the noise-reducing elements.

Figure 5.9: Publicly financed movable noise protection (noise shutters) placed in front of an existing living room window on a residential building along an arterial road in Copenhagen.

An example of how a road administration can follow and monitor the development of noise can be observed in the new Dutch scheme for monitoring noise along the national highway network [61], which is called SWUNG (Working Together on New Noise Policy). For every 100m of the highway system, a monitoring point at some distance from the highway has been defined. The noise has been predicted at all these monitoring points. Data on the predicted noise for these 60,000 monitoring points are publicly available on the Internet. A noise limit value has been defined for each monitoring point. This limit value is 1.5dB higher than the predicted noise levels in 2008, when the system was first implemented, in order to provide 'room' for some development in the traffic and noise. Every year, the noise is predicted at all of the monitoring points, based on the development of traffic volume, percentage of heavy vehicles and speed. If and when the noise limit at a monitoring point is exceeded, the road administration is obligated to take action to reduce noise.

5.2 Planning of noise abatement along existing road networks

The possibilities of reducing noise along existing roads often depends on additional funding. Such funds can be included in budgets allocated for noise abatement along the existing road network in order to reduce the number of noise-exposed dwellings. There may also be special cases where noise abatement needs to be established at existing roads for legal or political reasons. In such cases, construction of noise barriers and implementation of façade insulation are generally obvious choices for noise abatement.

Good and well-documented planning is required in order to invest the money set aside for noise abatement in the most efficient way. Some general goals and criteria for the selection of where to prioritise noise abatement can be defined; the following are some examples:

- The focus is on dwellings with an L_{den} of greater than 65dB or greater than 70dB;
- The focus is on dwellings with an L_{night} of greater than 50dB or greater than 55dB;
- In a noise barrier project, the dwellings receiving the largest noise reduction will have a noise reduction of at least 5dB;
- Projects with the lowest cost per reduced dB per dwelling have highest priority;
- Projects with the lowest cost per reduced NEF or other indicators for accumulated noise exposure (refer to Section 3.4 and Annex B) have the highest priority;
- Priority is giving to noise barriers, as they reduce noise both in outside areas and inside dwellings;
- Only projects where more than 20 dwellings (or another number) receive noise reduction are prioritised;
- Façade insulation is only used where it is not cost effective to use noise barriers;
- Façade insulation is only used where it is technically impossible to use noise barriers;
- Façade insulation is used as a supplement to noise barriers to ensure an acceptable indoor noise level in dwellings; and
- Priority is given to façade insulation solutions presenting a noise reduction of at least 5dB.

A strategy for noise abatement could be defined using a series of the previously mentioned goals and criteria. The noise mapping performed, according to the END (refer to Section 7.1), could be used as a first pass to select residential areas with high noise exposure where noise abatement can be considered. In the selected areas, it is necessary to perform detailed analysis of the possibilities for applying noise barriers or façade insulation, including detailed predictions of the noise-reducing effects and estimates of the costs of each project. This can also include hotspot identification (refer to Section 3.4) and CBA (refer to Annex A), which can be used to perform the final prioritisation and ranking of the selected projects.

Figures 5.10 and 5.11 illustrate examples of a noise barrier and façade insulation, performed by the road administrations along existing highways.

A strategy for the noise abatement along existing roads can be defined in the noise action plan, developed by the road administration (refer to Section 7.3).

Figure 5.10: Noise barrier of structured concrete, constructed by the road administration, along an existing highway in Tallinn, Estonia, to protect an area with villas.

Figure 5.11: Façade insulation of dwellings along existing highway in Norway, financed by the road administration (photo by the Norwegian Public Roads Administration).

If public funds are invested in noise abatement along existing roads, it is necessary to define procedures and responsibility for the ongoing maintenance of the noise barriers, façade elements, etc.

5.3 Prevention of new noise conflicts

The order of magnitude of the noise issue along a given road section can be increased in two different ways as follows:

1. The noise level can be increased due to increased traffic, higher speeds or changing to a noisier pavement type. These are factors for which the road administration has the responsibility, even though ongoing increasing traffic volume can be difficult to control as this is normally driven by the general development in the society; and
2. The number of noise-exposed dwellings along a road section can be increased if new housing is constructed in the noise zone of influence. The planning and approval for new house construction are normally the responsibility of the local municipalities.

It must be in the clear interest of the road administrations, especially at the national and regional levels, to avoid an increase in the number of noise-exposed neighbours over the existing situation. Over time, an increase in receptors will result in both the demand for and the cost of noise abatement.

5.3.1 Increased noise due to changes in road usage

Over several years or even decades, there have not only been changes in the land usage near the roads, but also in the traffic volumes and the fleet composition using roads. Several elements can lead to a higher noise emission of the road which are not in the sphere of influence of the road authorities, mainly including the following:

- A higher number of passenger cars;
- A higher number of trucks;
- Changes in the vehicle fleet which affect the noise emission, such as new tyres, bigger engines, etc.; and
- Changes in traffic flow resulting, for example, in higher congestion.

In particular, even a small annual rise in traffic volume can lead to higher numbers of traffic over a few decades. The resulting congestion cannot always be resolved without road enlargements, which can lead to new conflicts when the road gets closer to noise-sensitive areas in the surroundings. The planning of road enlargements is described in Chapter 4.

As the purpose of national roads is to enable mobility for a high number of users, a reduction in traffic, through limitations (not enlarging the road, thereby limiting its capacity) or obstruction (speed limits, removal of possible relations in the network) for example, is generally not considered.

Figure 5.12 illustrates an example from Denmark. In a period of 10 years, from 2004 to 2014, traffic has increased by 35% on motorways. Such an increase corresponds to increased noise of approximately 1dB. The figure also shows the purpose of motorways, i.e. to carry the development of road traffic.

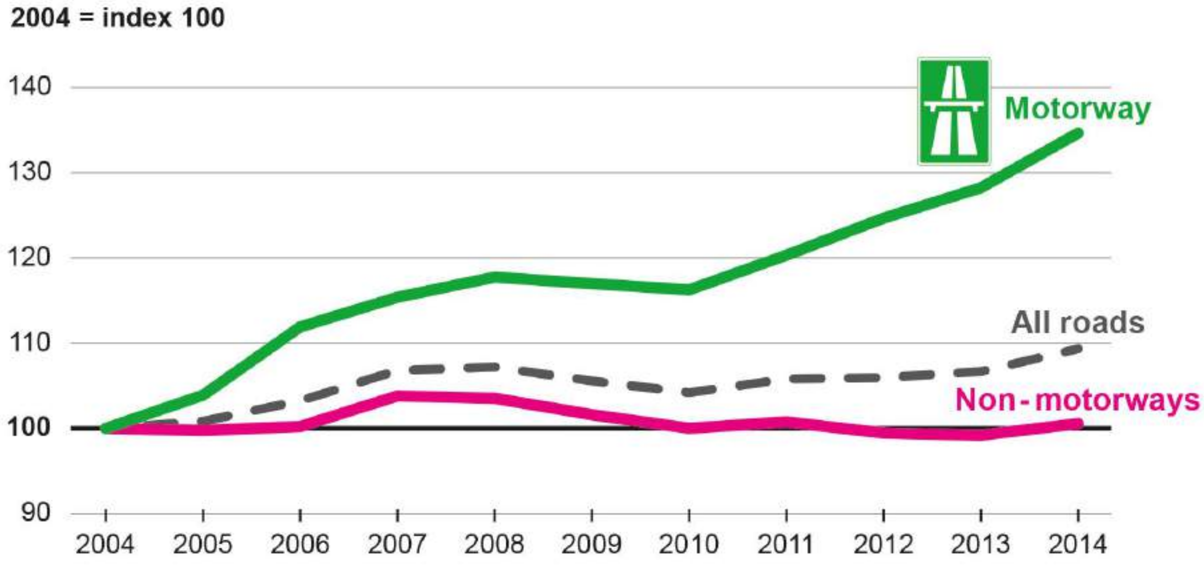

Figure 5.12: Example of development in traffic on motorways in Denmark compared to other roads.

A possible alternative to enlarging or widening roads near areas sensitive to noise could also be to construct new roads to reroute a portion of the traffic flow. In particular, this can be identified as a solution where a high volume of traffic takes the same route (especially trucks). An example is a new connection of the Harbour of Bremerhaven to the highway instead of an improvement of the existing road (refer to the example in Annex C).

Therefore, measures need to be taken into account that counteract the higher usage of a road. These can include the following:

- Noise-reducing pavements;
- Speed limits;
- Noise barriers and/or earth walls; and
- Façade insulation.

Speed limits may be an alternative for stretches of road which do not require an expansion but result in noise conflicts due to increased traffic. These could also lead to a slightly lower traffic volume, but side effects such as increased travelling time, etc. should always be considered.

Generally, planning of roads takes future traffic predictions into account (refer to Section 4.2.1), with a horizon of 10–20 years. In noise-sensitive areas, a longer time horizon could also be applied to help prevent future noise conflicts.

As discussed in Section 5.1.3, the new Dutch scheme, SWUNG, for monitoring and handling noise along the national highway network [61] may be considered. For every 100m of the highway system, a monitoring point at some distance from the highway has been defined. The noise has been predicted at all of the 60,000 monitoring points, and these data are publicly available on the Internet. On this background, a noise limit value has been defined for each monitoring point, which is 1.5dB higher than the predicted noise levels in 2008 when the system was initiated. This provides 'scope' for some development of traffic and noise. Every year, the noise is predicted at all the monitoring points based on the development of traffic volume, percentage of heavy vehicles and speed. If and when the noise limit at a monitoring point is exceeded, the road administration is obligated to take action in order to reduce the noise.

5.3.2 Increased housing near roads

Land-use planning offers the greatest potential for minimising conflict between road noise and sensitive land uses, followed closely by the development of appropriately designed and noise-insulated buildings. However, it is a challenge for road administrations to ensure that new dwellings constructed in the noise influence zones around the existing roads and highways are carefully protected against noise, both at the time they are built and in the long run.

There is often a local interest in or demand for developing vacant land and constructing dwellings in the vicinity of towns and existing residential areas; vacant land can often be found around the road infrastructure. Generally, such urban development requires a municipal planning process; however, legislation and practices for such planning varies in different regions of Europe. This planning process may also include public hearings, as well as hearings involving other public institutions and the private sector. Hearings involving other public institutions may also include regional and NRAs, and in this way they will be informed about new urban development around their roads.

Figure 5.13: New residential area constructed along an existing main road. As part of the project, the developer has constructed and financed a combination of noise barriers and earth walls.

In order to fulfil relevant noise guidelines, noise protection can be integrated into urban development projects; a series of measures can be used, as follows:

1. Increasing distance to main roads;
2. Noise barriers and/or earth walls (refer to Figure 5.13);
3. Façade insulation; and
4. Using buildings and appropriate building designs along roads as noise barriers.

Noise barriers can be destroyed, for example, by storms and result in a degradation in acoustic performance [57]; thus, NRAs should consider financing for the future. After several years, a contractor developing a residential area may no longer feel responsible for noise protection or the company may even be liquidated. The party responsible for the maintenance and possible reconstruction should be identified at the beginning of the planning. This responsibility could naturally be given to the owners of the new residential buildings. This needs to be formally secured in the legal requirements for the new buildings. In some cases, the municipality could be considered responsible due to being deeply involved in the planning and authorisation process. The municipality can also benefit from several related taxes.

Façade insulations can also be affected by ageing. In recent years, higher requirements, for example, for thermal insulation have also led to the renovation of windows. As the windows and façades are the responsibility of the house owner, they should be well informed on the costs involved for a higher level of noise insulation. This also applies for later sales of houses.

In principle, the possibility that new housing projects will not fulfil the noise guidelines of the road administration cannot be excluded. If this is the case, the road administration will have noise-exposed neighbours, which may result in complaints from the new residents and demands for noise abatement which must be handled. It should be noted again (as in Section 4.3.1) that noise limits and guidelines are often defined at noise levels where 5 to 10% of the population can be expected to be very annoyed by the road noise. Generally, noise limits and guidelines do not reach a zero-effect level. Therefore, noise complaints can be expected from the neighbours of newly constructed residential areas even when limits and guidelines for noise have been followed.

To develop new dwellings along a motorway and protect existing dwellings with house ends turning towards the motorway (and therefore have two noise-exposed façades), a so-called ‘building snake’ has been planned along a highway in Denmark (refer to Figure 5.14). This will function as a noise barrier between the motorway and the existing residential housing. The façade towards the motorway will be noise insulated, and the apartments will be oriented away from the motorway to the ‘quiet side’ of the building.

Figure 5.14: A new 'building snake' (grey blocks) will form a noise barrier between the motorway and the existing residential housing [62].

5.3.3 Options for conflict prevention

Options for procedures and practices which may be used by road administrations to actively avoid too-high noise exposure in new residential areas along their road network are as follows:

1. According to the EU END [14], road administrations have to produce new or revised noise maps and noise action plans every fifth year for their road network (refer to Chapter 7). In this process, the road administration may contact and work together with the municipalities where roads pass through. In some countries, such cooperation may already have been established. This could be used as an opportunity to clarify the need for noise protection of new residential developments along roads;
2. The road administration could establish a forum for cooperation with municipalities where roads pass through. Such cooperation may already exist in some countries. In such a forum, noise and noise protection of new housing projects could also be placed on the agenda;
3. The road administration could establish a formal procedure to request municipalities to send plans for residential development along their roads for consideration. In such a process, the road administration can evaluate noise and other relevant factors and provide feedback to the municipality. This has been implemented, for example, in the German building codes [63] in Section 4 as 'TöB-Beteiligung' (TöB: 'Träger öffentlicher Belange'; participation of public agencies such as police, regional and federal authorities, public utilities companies, etc.).

6 Noise in the road construction process

One of the greatest challenges facing urban highway construction projects, as well as construction projects near areas for recreational and holiday use, is the need for planning the mitigation of construction related noise. Although construction noise is temporary or short-term in nature, it may adversely affect nearby property owners, residents, users and wildlife. Managing construction noise is also one of the first occasions after the planning process where the road administration can start to build and establish a good relationship with the neighbours of a new highway.

The mitigation of construction noise may prove challenging as the construction equipment and processes are generally loud and mobile in nature.

This chapter presents construction noise mitigation tools and provides insight into the construction noise criteria. Furthermore, modelling and monitoring of construction noise and the public participation process are described.

Funds should be reserved in a road construction project's budget for noise management and prevention, monitoring, public information and cooperation with neighbours, temporary reallocation of tenants, etc.

Air pollution from machines and equipment with combustion engines, as well as dust and vibrations from working and construction processes, can also cause disturbance and annoyance for the neighbours of the construction site. These matters are beyond the scope of this chapter, but their interrelationship with noise should be considered during the EIA process.

This chapter is partially developed on the background of the best practices already used in European countries. These experiences are described in Section 3.3 of the ON-AIR status report 'Investigation of noise planning procedures and tools' [9].

Figure 6.1: New urban highway under construction as a cut-and-cover process in densely built-up residential area in Copenhagen, Denmark. Temporary wooden noise barriers have been established to reduce the construction noise.

6.1 Noise guidelines and limit methods

Noise, in relation to construction processes, can be limited by emission limits for the equipment and processes, as well as by noise limits at the receivers. Emission limits provide an easy method of lowering the noise emitted by machinery and thus the noise level at the receiver.

In May 2000, the European Parliament and the Council of the EU introduced Directive 2000/14/EC on noise emission in the environment by equipment for outdoor use [64]. The main elements dealt with in this directive include 57 types of equipment, mainly used on construction sites, parks and gardens. Via contract specifications and special provisions, the utilisation of equipment in compliance with the directive can be regulated in the planning and design phase of a road project.

On more extensive construction sites, an emission limit may not be sufficient. In these instances, a noise limit at the receiver or site boundary can be selected or demanded by law. Construction noise guidelines and limit values can refer to the specific land use, in the same manner as in detailed planning of road projects (for more information, refer to Sections 3.1 and 3.2). The limit values may also apply to different indicators, such as maximum or peak levels, as well as the average sound level for a given time period.

Table 6.1 presents an example of how maximum noise levels may be defined at receiver points. In the example, an average noise level (L_{Aeq}) of 65dB is allowed for a maximum exposure time of 8 hours, within the time period 07.00–18.00. For the night time period (22.00–07.00), a maximum exposure of 0.5 hours is allowed, with an average noise level of 40dB. The maximum noise level is limited to 80dB during daytime periods and 45dB during night time periods. In this example, construction noise is not allowed on weekends or public holidays; however, limits may also be defined for these periods, if relevant, taking into account that these are periods when people are typically at home and engaged in recreation.

Table 6.1: Example of maximum noise level at residential receiver points which must not be exceeded for a construction site. The number of hours may define the length of a measurement interval for the L_{Aeq} level.

Time Period	Average Noise Level [dB]	Maximum Exposure Time [h]	Maximum Noise Level [dB]
Monday–Friday 07.00–18.00	65	8	80
Monday–Friday 18.00–22.00	55	4	70
Monday–Friday 22.00–07.00	40	0.5	45

Another possibility may be that construction activity is generally not allowed during night time or weekend periods. The limit values could also be defined according to the total duration of the construction process so that the criteria are more restricted for longer term activities.

Construction noise regulation varies between European countries. In relation to environmental protection, a construction site is generally regarded as an industry. It is often the municipality which defines the noise limits and the regulative framework; furthermore, it is generally the responsibility of the project administration (road owner or road owner representative) and the contractors to comply with the established noise criteria. A Construction Environment Management Plan may be used to regulate the environmental consequences of a road construction project. Consulting companies may be hired to establish noise-monitoring systems.

Generally, construction work is regulated by limit values which contractors must adhere to. Typically, a noise plan has to be developed by the contractor and approved by the relevant authority, which may be the project administration or the municipality. The day-to-day performance is evaluated using noise-monitoring systems.

6.2 Prediction of construction noise

To determine the noise impact of a construction project on sensitive areas, noise predictions are used in the same way as noise prediction from other industries. For example, the ISO 9613-2 [65] provides methods for calculating outdoor sound propagation. Different official methods may be used within various European countries.

Commercial noise prediction programmes (such as SoundPLAN, IMMI, CadnaA, etc.) allow the modelling of all relevant noise sources such as construction machines and processes, taking into consideration the duration of the respective activities, the location of the equipment and time of construction (day, evening or night time). Therefore, the noise levels for nearby receivers (such as residential buildings) can be estimated. Some consulting companies specialise in such noise prediction and mapping.

It is possible to determine if (or to what extent) noise abatement is required, once the calculation results have been evaluated and compared to the legal limits and/or guideline values. Furthermore, by changing certain parameters, such as equipment types and working locations and times, it is possible to determine alternative design and operation options for the construction site to provide the best noise management results. However, noise modelling software has certain limitations in accuracy. All such programmes rely on the user-defined noise emission levels and the estimated usage for each piece of equipment, as well as the time of day it is used and for what period. Therefore, the resulting noise levels are highly dependent on the accuracy of the input data (sound power, sound pressure levels, etc.). In practice, technical studies and catalogues with the construction equipment emission levels are often used, such as the German 'Technischer Bericht zur Untersuchung der Geräuschemissionen von Baumaschinen' [66].

Figure 6.2: A given excavator has a certain noise emission level. The total noise contribution from this machine also depends on the number of machines used, the duration of the working process, the time of the day and the distance to noise receiver points.

6.3 Abatement of construction noise

Mitigation measures can be divided into active and passive noise protection measures. Active measures include all activities during the planning and design phase, as well as mitigation measures on the source and along the path of sound propagation. In contrast, passive measures are those implemented directly on the noise receiver.

During the selection of appropriate mitigation strategies, the following elements are generally taken into consideration: expenses, applicability, possible noise reduction and the effect on the overall project operation [67]. Nevertheless, every construction project is different and constantly changing. Therefore, all noise control solutions have to be adjusted for the specific situation. Most of the presented mitigation options can be employed independently or in combination, depending on the scope of the project and the desired results.

It must be emphasised that if construction noise is already taken into consideration in the planning and design phase of a road project, prevention of noise will generally be more limited yet more effective (refer to Section 4.3.3). Therefore, construction noise can also be included in the public participation process during planning (refer to Chapter 8). Cooperation and communication between road construction organisations and neighbours should be established at an early stage. This may reduce complaints and conflicts during the construction process and facilitate enhanced day-to-day cooperation between contractors and neighbours.

6.3.1 Active mitigation measures

6.3.1.1 Mitigation options in planning and design phase

It is important to consider construction noise during the early project stages. As the potential magnitude of the construction noise impact on a community may not be known early in the project development stage, measures that can be implemented during the design phase may reduce the anticipated noise impacts at sensitive receptors. Examples of mitigation measures in the design phase are listed in the following sections.

Design considerations and project layout:

- Storage areas for spoil and rock material could be located further away or be used as a temporary noise barrier. Waste or other construction materials can be positioned between noise sources and receivers, providing necessary shielding for the sensitive areas.
- Intermediate or haul roads for construction trucks and dumpers can be planned so that there is a suitable distance from noise-sensitive areas.
- Road diversions can be designated in locations where the noise impacts caused by construction truck traffic may be reduced.
- Existing natural or artificial barriers such as ground elevation can be used; existing buildings, noise walls and other structures should be considered in this phase.
- Construction of planned noise barriers could be carried out in the initial construction phase of the project, providing necessary protection for the following construction stages.
- The existing road network may be used for transport of material and machinery to and from the construction site; therefore, mandatory routes, causing the least annoyance and disturbance, can be planned.

Contract specifications and special provisions:

- Contract specifications and special provisions are typically produced during the design stages of project development and may be included in the project plans and contract documents [67]. The use of specific construction equipment could be defined in this stage.
- Contract specifications can be put in place requiring that the contractor develop a noise management plan (environmental operating plan) and employ construction methods with less noise. An example of the latter is the replacement of old vehicles and equipment with newer ones.
- The contract could stipulate contractors to participate more actively in noise mitigation or include penalties in cases where prescribed conditions are not met.
- In larger projects, an integrated part of the contract could be discussions and detailed planning of practical solutions between the road construction authority and the winning contractor; the objective being to develop improved and more cost-effective solutions, prior to commencement of construction work. Previous experiences and new ideas from the contractor can be discussed and may be integrated into the project. This can be a method/procedure used to establish positive, joint cooperation between the contractor and construction organisation. This process could also include the planning of construction noise management and other disturbances to the neighbours.

The sequence of operations can be planned to optimise the noise exposure for the receivers. Although the average noise level stays identical for the period, the maximum noise level or the duration of noisy operations can be optimised/reduced as follows:

- If several noisy operations are scheduled at the same time, the resulting noise levels will not be much greater than for separate operations. Therefore, the duration of noisy activities can be reduced with the trade-off of a higher noise level during those activities;
- By separating noisy operations, the noise level during each operation can be lowered with the result of a longer operational period; and
- Although it is preferable to conduct the main construction activities during the day, in some case it may be more beneficial to work 24/7 in a shorter period to complete a noisy operation as opposed to having daytime construction noise for a long period.

Alternative construction methods:

- Using different construction techniques may be an effective method of dealing with construction noise, as the same task may be undertaken in a less noisy manner.
- Impact pile driving in noise-sensitive areas should be avoided, whenever possible. Pile drilling or the use of a sonic or vibratory pile driver can be a quieter alternative where the geological conditions permit their use.
- Specially silenced equipment can be used, such as sound reduced and enclosed air compressors and mufflers on all engines [68].

6.3.1.2 Mitigation measures at the source

As a general principle, it is recommended to use the least polluting processes and machinery available to improve the environment. This is also a principle to integrate into the planning of abatement of construction noise.

Noise control at the source has proven to be the most cost-effective form of noise mitigation. Noise created at construction sites depends highly on the type of equipment used and its operation. Such noise can generally be divided into that generated by stationary and mobile equipment.

The first task in noise mitigation at the source is the selection of adequate equipment. Whenever possible, preference should be given to quieter, newer equipment, as mentioned previously. As new equipment has to meet higher technical standards and does not have problems with worn and damaged components, it is generally quieter than used equipment. However, the acoustic performance of older quipment can be improved with regular maintenance. Simple modifications such as the addition of new mufflers or sound-absorbing materials can make construction machines less noisy.

Construction noise is largely generated by the operation of engines. This can be reduced by using adequate mufflers.

Stationary noise sources such as pumps, compressors and generators should be placed as far as possible from the sensitive areas. They are suitable for enclosing and this method should always be considered for stationary equipment. Temporary noise casings can be made of simple construction material. The noise reduction could be reinforced with sound-absorbing materials.

Noise mitigation of mobile equipment can be more complex, as simple enclosure is not viable. The 'FHWA Highway Construction Noise Handbook' of the United States (U.S.) Department of Transportation [67] introduces the following solution: 'Use of the special sound aprons can be one option. Sound aprons generally take the form of sound absorptive mats hung from the equipment or on frames attached to the equipment. The aprons can be constructed of rubber, lead-filled fabric, or PVC layers with possibly sound absorptive material covering the side facing the machine'.

6.3.1.3 Mitigation measures along the path

As in operational traffic noise control, mitigation measures along the sound propagation path may be effective in construction noise mitigation. Barriers can take the form of natural, temporary (refer to Figures 6.3 and 6.4) or permanent shielding. Temporary barriers may be decorated by local graffiti artists, giving them a more pleasant appearance and possibly preventing 'anarchistic' graffiti (refer to Figure 6.5).

Figure 6.3: Temporary 2m high noise barrier of plywood panels along highway enlargement project. After the construction work, it was replaced by a permanent noise barrier. The low concrete wall in the front is the foundation of the permanent noise barrier.

Figure 6.4: Temporary 4m high wooden noise barrier with absorbing and noise-reducing mineral wool at the construction side of the barrier. The barrier is bending towards the construction site to increase the noise reduction.

Figure 6.5: Temporary wooden noise barrier at an urban highway construction site with 'anarchistic' graffiti (left) and a barrier decorated by a local graffiti artist (right).

6.3.2 Passive mitigation measures

Passive protection is the final alternative in construction noise control and is recommended in cases where active noise protection is neither cost efficient nor provides the necessary protection of sensitive areas.

Mitigation measures on the receiver can range from building insulation to the temporary relocation of residents. With the relocation of residents, the respective noise receivers are eliminated, which allows continuous operation and speeds up the construction process. Temporary relocation of citizens has a large impact on people's daily lives, but may be necessary in exceptional circumstances. Another possibility is to offer alternative night-time accommodation during unavoidable noisy night-time activities, e.g. in local hotels. Establishment of a quiet 'public living room' or a neighbouring café where residents can have a quiet period during day and evening time may be considered.

6.4 Public participation and information

Strategic consultation, close coordination and cooperation with the public in all project stages are essential for the success of a project. To manage a successful public participation process, a public involvement concept should be developed (refer to Chapter 8).

The proposed concept should focus on all involved parties such as residents, commercial stakeholders, citizens, tenants and owners associations, institutions/schools, etc. An important task in the public participation process is to provide clear information about the construction project, as well as all details concerning the relevant technical planning/construction process, to address all concerns, fears and reservations regarding the project. Furthermore, the public should be informed about the timeframe and regularly kept up to date in case of changes [69].

A well-planned and well-conducted public participation process in the construction phase can result in improved conditions and well-being for the neighbours, as well as less expense and a more positive reputation of the road project.

Depending on the budget and the extent of the construction site, a public involvement concept could be developed in cooperation with specialised agencies which have experience in participatory processes, facilitation, conflict management and public relations. Specialised agencies should provide additional support to the project team in the most important steps of public participation.

Some of the central elements of an effective participation process are as follows:

1. Definition of clear policies and procedures in the public participation process;
2. Ongoing internal communication between contractors, the project team and specialised agencies;
3. If necessary, a dialogue with the relevant authorities and administrations, suppliers, retail representatives and other groups, prior to the actual participation process;
4. Establishment of a clear press strategy;
5. Establishment of a digital participation platform (website) with complete, relevant and up-to-date information, through which stakeholders can lodge complaints and find answers to frequently asked questions;
6. Assignment of staff responsible for the communication process;
7. Organisation of public meetings and consultations;
8. Provision of information and press releases to the local media;
9. Regular documentation of the outcome of public meetings;
10. Public contribution to construction noise management and selection of the mitigation measures;
11. Selection of a staff member or group known in the residential area to be responsible for communication with the neighbours;
12. Establishment of a 24/7 hotline where people can lodge complaints and receive updated information on the ongoing work processes; and
13. Establishment of key contact persons among the neighbours or SMS/email lists where information on changes in working plans and activities resulting in noise can be distributed at all times.

Exceptional construction processes which are very noisy (e.g. demolition of concrete structures or blasting operations; refer to Figure 6.6) could draw the attention of stakeholders who may be included as spectators on site or by live web streaming. Such events may result in different view of the construction process, which is often only associated with annoyance and disturbance.

Figure 6.6: A noisy demolition of an old concrete bridge can be turned into a public event for the neighbours, perhaps by establishing platforms to view the work with guides explaining the work and serving grilled food and beverages (photo: DRD).

6.5 Monitoring of construction noise

To control the efficiency of planned noise abatement on construction sites, noise monitoring measurements can be used. Based on monitoring results, procedures may be adjusted and improved.

Prior to the construction process, background noise measurements should be conducted, as background noise levels serve as a reference level to which a comparison can be made. Measurement locations and time periods selected for measurement of construction noise should be the same as those used to determine background noise levels.

Generally, measurements of construction noise activities are conducted in exterior locations (refer to Figure 6.7). Depending on local procedures and regulations, such measurements may be taken at different locations, including the following:

- At the property line closest to the construction activity;
- At residences or other sensitive receptors; and
- At the point closest to frequent human activity.

Figure 6.7: A permanent, continuous noise-monitoring station at a residential building close to a construction site. The microphone is shown above and the data-collecting equipment and power supply are visible below.

The measurement and monitoring of construction sites can be carried out using a range of instruments, depending on the period over which the measurements need to be taken. Instruments used for this purpose can be divided into the three following groups:

- A handheld sound level meter with a variety of data output options suitable for measurement of equipment noise and some construction operations;
- Permanent, continuous noise monitoring systems (refer to Figures 6.7 and 6.8); and
- Automated monitoring systems.

An analysis of the measurement results can provide an overview of the noise situation during a construction process. These values should be stored and, if necessary, they can be presented on the project's website. If measurements are made publicly available, neighbours can follow the process and development of noise. The measurement results can also be used for documentation in cases where complaints about construction noise are raised.

Figure 6.8: Continuous noise monitoring systems overlooking the IKEA construction site in Hamburg, Germany.

7 Noise mapping and noise action planning according to the Environmental Noise Directive

This guidance book mainly focusses on how noise can be integrated into the planning and maintenance of road infrastructure. The guidance book is not intended to demonstrate how to perform noise mapping or noise action plans in accordance with the END, relating to the assessment and management of environmental noise from 2002 [14].

In the ON-AIR status report, practical experiences related to noise mapping and developing noise action plans from a series of European countries are presented [9]. In 2013, the CEDR working group on noise, published a report that also includes an evaluation and analysis of experiences concerning the implementation of the END in the NRAs within Europe [11].

The objective of this chapter are to describe how the END noise mapping and action planning can be used to support the integration of noise into the planning and maintenance of the road infrastructure.

The END aims to ‘define a common approach intended to avoid, prevent or reduce on a prioritized basis the harmful effects, including annoyance, due to the exposure to environmental noise’; this is consistent with objectives of this guidance book.

For NRAs, the work with noise action plans and noise mapping can be seen as an integrated part of the function of incorporating noise in the ongoing process of road maintenance, as described in Chapter 5. The development at noise maps and action plans is also a positive opportunity for the road administration to contact and engage in dialogue with the neighbours of the roads. A dialogue which can facilitate amicable neighbour relations will help to avoid complaints about noise and support improvement of the noise environment.

7.1 Noise mapping

According to Article 7 of the END, Member States have to produce strategic noise maps for major roads based on the common noise indicators L_{den} and L_{night}. In some Member States, NRAs are the responsible authorities in the process of noise mapping.

Noise maps must be produced every five years for roads with daily traffic of more than approximately 8,200 vehicles and for agglomerations with more than 100,000 inhabitants. However, a road administration can decide to perform noise mapping of the whole road network under its administration. Noise maps have so far been produced using the national noise prediction method (refer to Section 3.3) but according to the EU directive 2015/996 of 19th May 2015 on establishing common noise assessment methods [26], the EU Member States are required to use the CNOSSOS-EU method for road noise mapping in relation to the END from 31st December 2018 onwards.

It is important that the noise mapping reflects changes in the following from the noise mapping carried out five years ago (refer to Section 5.1.3):

- Traffic volume;
- Percentage of heavy vehicles;
- Actual speed;
- Distribution of the traffic volume over the 24 hours of the day (day, evening and night);
- Pavement type; and
- Construction of noise barriers.

Therefore, it will be possible to use the noise mapping to highlight and quantify the necessary improvements since the previous noise mapping, if any, or to show increasing noise caused by traffic development.

The first and second rounds of noise mapping have illustrated some of the challenges of END implementation, such as inconsistent approaches to mapping, lack of noise limit values and confusion amongst responsible bodies regarding the END requirements [9, 11]. However, noise maps have also affected the practice of noise management in the NRAs. According to the END, the first round of noise mapping resulted in traffic noise issues being made visible for the included national road networks. Based on the noise mapping results, NRAs were able to identify the most affected areas. In a similar way, noise maps can also be used in relation to the maintenance of the roads (refer to Chapter 5). When a road section is selected for pavement renewal, noise maps can be used to check how many noise-exposed households there are along this section and this information can be considered in deciding whether to choose a noise-reducing new pavement or an ordinary pavement (refer to Section 5.1.1).

7.2 Public participation in noise mapping

Article 9 of the END [14] requires strategic noise maps and action plans to be made available to the public; furthermore, they have to be clear, comprehensible and accessible.

Strategic noise maps have usually been published on the website of the responsible administration or on specialised noise-mapping portals [9]. Newspapers, public meetings and workshops have also been used as the main tools in the public participation process (refer to Chapter 8). Public participation could be structured as a process for the road administration to establish a forum for a dialogue with the neighbours of the roads where noise-related questions and complaints can be managed (refer to Section 7.3 on action planning). This could be used as input in the process of deciding whether to use noise-reducing pavements in road maintenance (refer to Section 5.1.1).

In the majority of Member States, the results of the noise mapping to date have generated a negligible response from the public, with the exception of Germany, where noise mapping triggers a strong reaction [9]. As a result, citizens often use noise maps as an argument when they complain about traffic noise.

7.3 Noise action planning

Amongst the actions required in the END is the ‘adoption of action plans by the Member States, based upon noise-mapping results, with a view to preventing and reducing environmental noise where necessary and particularly where exposure levels can induce harmful effects on human health and to preserving environmental noise quality where it is good’. A noise action plan is a document describing the actions a road administration will take to reduce noise in the environment of the roads. An overview of how the development of noise action plans are organised in different European countries can be found in [9,11]. According to the END, a noise action plan has to be developed every fifth year, covering roads with more than 8,200 vehicles per day and for agglomerations with more than 100,000 inhabitants. The action plan is typically developed on the background of the noise mapping performed according to the END [14].

A noise action plan can be passive and simply state that the administration does not plan to implement any noise-reducing measures. However, it can also be active, establish goals and/or limit values and describe actions to be taken.

The most significant activities of NRAs in drawing up noise action plans can be divided into three main categories, as follows:

1. Development of the noise action plans;
2. Revision of the noise action plans, prepared, for example, by the local/regional authorities; and
3. Assistance and consultation of local/regional authorities during the development of the action plan.

Generally, the role of the local and regional authorities in the noise action planning process is determined by the national legislation, which defines the authority responsible for the noise action planning. Therefore, the involvement of these authorities varies significantly amongst the European countries [9]. In most of these countries, NRAs have the leading role in the development and implementation of the noise action plans on national roads.

The focus of noise action plans is normally the existing road network on the background of the noise situation highlighted in the noise mapping. However, a noise action plan could also be used for defining overall noise strategies for construction of new roads, as well as for the improvement and enlargement of existing roads.

7.3.1 Content of a noise action plan

As guidance, the following list provides a series of goals and limit values with different levels of ambition:

- The number of dwellings exposed to >55dB (L_{den}) must not be increased;
- The number of dwellings exposed to >50dB (L_{night}) must not be increased;
- The number of dwellings exposed to >65dB (L_{den}) must be reduced by 5% within 10 years; or

- The number of dwellings exposed to >55dB (L_{night}) must be reduced by 5% within 10 years.

To fulfil the goals established in a noise action plan, different strategies can be used and combined, as follows:

1. If funds are available, active investment in noise abatement can be used for barriers, façade insulation, etc. (refer to Section 5.2);
2. Integration of noise in ongoing maintenance procedures of roads and areas surrounding roads, such as always using noise-reducing pavements when renewing pavements (refer to Section 5.1.1); and/or
3. Encouraging and supporting residents to take proactive actions such as installing façade insulation, local barriers, etc.

The construction of a new bypass road which relocates traffic from residential areas to areas outside the city is a measure that will often reduce the noise around parts of the urban road network. This is a measure that can be incorporated into a noise action plan, although such a measure will normally be a part of the general road planning and not the active consequence of a noise action plan.

In some countries, NRAs have funds allocated specifically for noise abatement along the existing roads (refer to Section 5.2). Such funds are typically used for noise barriers and possibly façade insulation. Priority may be given to measures with the greatest noise reduction potential which provide the best value for the money. Both low-cost measures and reduction measures at the source can be highlighted. The most common measures in noise action plans are noise barriers and noise-reducing road surfaces [9]. CBA can be used for the evaluation of the different noise-reduction measures in the process of noise action planning (refer to Annex A).

An active tool of noise abatement in a noise action plan can involve a policy for integrating noise in the road and pavement maintenance procedures. One strategy could be to apply noise-reducing pavements at road sections passing residential areas when pavements are required to be changed (refer to Section 5.1.1). Therefore, the cost of noise abatement could be integrated into the road maintenance budgets.

7.3.2 Encouraging residents to perform noise abatement

A third type of noise abatement measure can be active involvement of house owners and residents. The main idea is to actively inform people of how they can reduce noise and annoyance by engaging in noise abatement activities that they also finance. The technical and economical possibilities for noise abatement are not always common knowledge. A secretariat could be established within the road administration whose employees mainly deal with information, planning, initiating and managing local efforts. The following could be encouraged:

- When rebuilding and enlarging existing housing, new buildings, garages and covered bike parking can be placed so they function as noise barriers, reducing noise in gardens, on terraces, etc.;

- Noise reduction may be achieved by changing to specialty noise-insulating windows which can be financed by the annual maintenance budget; this could also finance additional noise-reducing projects. If this is undertaken when windows have to be renewed, the cost will be marginal; furthermore, such windows will generally reduce the cost of heating;
- Local noise barriers around gardens and terraces can be built;
- If new fences have to be established or old fences renewed, the new fences can be built so that they function as noise barriers; often, this will not increase the cost dramatically; and
- Planning and constructing noise barriers with photovoltaic panels, financed by the residents, where the electricity produced over the years can partly (or fully) pay for the investment.

Another measure of a noise action plan may be planning where an earth wall can be placed and designed to provide noise reduction in a residential area. In this case, vacant land also has to be reserved for the earth wall. The construction of the earth wall could then be performed over a long period of perhaps 10 or 15 years, using surplus dirt (and rock) material from road projects and other construction projects in the municipality (refer to Section 4.3.3).

7.3.3 Framework for the systematic management of road noise

The action planning approach may be used to provide a framework for the systematic management of road noise in the road administration. The noise action plan can be used as the document where the following strategies of a road administration for handling noise may be outlined:

1. Defining guidelines for noise in new road projects (refer to Chapter 4);
2. Defining guidelines for noise in road enlargement and improvement projects (refer to Chapter 4);
3. Defining guidelines and procedures for handling noise in road maintenance activities (refer to Section 5.1);
4. Defining guidelines for noise abatement along the existing road network (refer to Section 5.2);
5. Defining guidelines and procedures for handling noise in road construction activities (refer to Chapter 6); and/or
6. Guidelines and procedures for avoiding the creation of new noise-exposed housing along roads (refer to Section 5.3).

These strategies can be used as overall guidelines for the handling of noise in the ongoing road planning, the planning of maintenance activities and the daily handling of noise issues.

7.4 Public participation in noise action planning

According to Article 8 of the END [14] on action planning, 'Member States shall ensure that the public is consulted about proposals for action plans, given early and effective opportunities to participate in the preparation and review of action plans; that the results of that participation are taken into account and that the public is informed on the decisions taken'.

To date, public consultation has mainly been conducted through the official web presentations of the local authorities and NRAs responsible for noise mapping and action planning. However, public meetings and discussions have been more the exception than the rule [9]. Noise action plans generate a very low response, indicating poor public involvement. Most of the received responses and comments focus on local noise problems and demands for noise reduction [9].

The public participation in noise action planning could be actively used as a means for road administrations to establish a positive dialogue on noise with the neighbours of the roads, as follows:

1. Neighbours have a formal channel for expressing their views and satisfaction/dissatisfaction, concerning the noise environment;
2. The road administration has the opportunity to explain what is technically and economically possible;
3. A dialogue with the neighbours on selection, periodisation and financing noise abatement can be performed;
4. Partnerships can be established where the road administration assists with the planning of noise abatement and provides technical advice, and where the citizens finance the noise abatement through efforts such as façade insulation, short local barriers, etc.;
5. Partnerships can be established between the road administration, the municipality and the citizens to take measures such as reserving vacant land for constructing a noise embankment using surplus dirt over a 10-year period; and
6. The road administration can provide technical advice on integrating noise when citizens renew fences, windows, etc..

Such activities can all be used to create enhanced neighbour relations between citizens and the road administration, which may reduce complaints and alternatively facilitate positive cooperation wherein the two groups manage noise issues together.

7.5 Common data usage and synergies

As both the END and the national noise prediction methods are based on a 3D noise propagation model, many similarities in data usage exist. Both methods require a digital model which includes terrain elevation and features (e.g. ditches and embankments), buildings and other obstacles or reflecting elements (depending on the national methods). As CNOSSOS-EU [25, 26] is to be implemented for the END by 2018 as a new noise prediction method, the requirements for noise mapping have changed for the authorities responsible for noise mapping.

The DISTANCE project [49] has established the data requirements for future noise mapping and action planning in their report 'Issues and assessment of data types related to CNOSSOS-EU requirements'. Apart from the list of required data, the project also analysed whether the NRAs were prepared for the new requirements arising from CNOSSOS-EU and summarised the tasks which need to be performed by the NRAs.

7.5.1 Data sources

In addition to the new requirements for future use of CNOSSOS-EU, a great deal of data (on buildings, terrain, road alignments, etc.) already exist. According to the END, noise mapping must be undertaken every five years for presumable most of NRAs road network covering a large area; thus, it is advised that the data is not just compiled once for a noise mapping.

Data originating from the NRAs such as road information (alignment, speed, road surface, etc.) could be extracted from pre-existing geographic information systems (GIS). If some data are missing from such a system, a link to a PMS, for example, may be used so that some additional information can be accessed automatically.

For other data provided by land surveying offices, for example, methods can be developed to allow standardised input into noise prediction, whenever necessary. However, this requires external data providers to maintain a standardised format, as changes in format and access can render previously successful methods useless.

Beyond the road infrastructure and general information on buildings and terrain, there is often a lack of available data in relation to noise barriers. Several different authorities may be responsible for a noise barrier, such as NRAs, local authorities, railway companies or even housing developers. It is advised that, whenever possible, NRAs should try to keep track of their own noise barriers as well as noise barriers built in the vicinity of national roads; these could also be included in existing GIS for their own noise barriers.

Lastly, it is advised that all data created in the final planning process of a road (road alignments, noise barriers and road surfaces) are also transferred to other databases; as a result, they can be used for updates in noise mappings.

Further information on the use of GIS in noise mapping can also be found in 'Noise Mapping in the EU – models and procedures' [33].

7.5.2 Use of data for National Road Administrations

In addition to the noise mapping according to the END, the extensive data existing for this purpose can also provide a basis for further assessment. This assessment can include both possible noise mitigation measures following the results of noise mapping/noise action planning and feasibility studies, etc. Even for the early stages of noise assessment, the data from END noise mapping can provide enough detail to perform first analyses on noise impacts.

The data resulting from noise mapping and noise action planning, such as façade levels or hotspot analyses, can also be used for considerations of the NRAs. This could represent additional criteria on where and when to implement noise-reducing road surfaces, etc.

7.5.3 Traffic data

While noise mappings are based on an analysis of the current situation instead of a prediction of traffic for the future, traffic data for the noise mapping can also be used as input data for a traffic model or a plain traffic prediction. In contrast, road infrastructure can provide data on traffic counts which could be used for the noise mapping process.

8 Public participation

Public participation helps to ensure that decisions are made with public needs and preferences taken into consideration. Involvement from the early phases of road projects brings diverse view points and values into the decision-making process, enabling agencies to make informed decisions. The interaction and knowledge exchange may also build trust and mutual understanding between the road administration and the public. It may even provide neighbours to roads with a feeling of ownership related to noise abatement measures such as barriers or façade insulation and equip the public with more realistic expectations concerning the noise environment that will result from a new project. This chapter is partly developed on the background of practices already used in European countries. These experiences can be found in the ON-AIR status report [8].

8.1 EU directives stipulating the frames for public participation

In the European context, public participation is fundamentally linked to the Aarhus Convention (EU Directive 1998 [6]). This was implemented in 2001 and officially named the Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters. As a result of the Convention, the parties are required to facilitate the effectiveness of national, regional and local authorities in maintaining a set of public rights. The first of these is the right of everyone to receive environmental information held by public authorities. The responsible parties are obliged to continuously disseminate environmental information and provide information requested within one month. Relevant types of information concern the state of the environment and human health and the policy being implemented. The second right established by the convention is the right to participate in environmental decision making. Public authorities are to put arrangements in place to ensure that affected people and environmental non-governmental organisations may comment, e.g. on project proposals and plans. The comments put forward are to be considered while decision making. The third right involves the ability to challenge public decisions if these are not in accordance with environmental law or the two previously mentioned rights.

As described in Section 4.2, an EIA is a tool for integrating environmental concerns into decision-making processes. EIA is integrated in the EU Member States' national legislation and procedures. To ensure a functional EIA processes, the EU Directive (EIA Directive 2014) [5] describes the requirements concerning the involvement of the public. Here, it is stated that once a decision to allow for or refuse development has been made, the public must be informed in accordance with national procedures. For example, when a project is approved, it is necessary to publish information about the environmental conditions attached to the decision. Furthermore, strategies intended to avoid or reduce (if possible) negative environmental effects must be described. This includes both noise exposure in the surrounding areas of a new road and noise consequences along existing roads where traffic conditions may be affected by a new road project.

It is the responsibility of the Member States to determine the detailed arrangements for informing the public; this is undertaken through publication in a local newspaper or other local media, via the Internet, direct public consultation, etc. The essence is that the public should receive sufficient information about the planned development. This also means that relevant information is required to be electronically available to the public. Moreover, the directive emphasises the need for reasonable timeframes, allowing for the members of the public to prepare and participate effectively in the environmental decision making.

Public participation is also anchored in the EU Directive 2002/49/EC; referred to as the Environmental Noise Directive (END) [14] (refer to Chapter 7). The END is integrated in the EU Member States' national legislation and procedures. Concerning the assessment and management of environmental noise, including road noise, the END aims to 'define a common approach intended to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to the exposure to environmental noise'. Throughout the directive, public participation and the need to ensure that information relating to noise (and its effects) is available and emphasised. With regard to noise mapping and noise action plans, the END states that they should be disseminated to the public and that the information is clear, comprehensible and accessible. Furthermore, Member States are requested to ensure that the public is 'consulted about proposals for action plans, given early and effective opportunities to participate in the preparation and review of the action plans, that the results of that participation are taken into account and that the public is informed on the decisions taken' (Directive 2002/49/EC, Article 9, paragraph 7) [14]. In addition, in relation to noise mapping and noise action plans, reasonable timeframes, allowing for sufficient time for each stage of public participation, are emphasised.

8.2 The reasoning behind public participation

Public participation has been emphasised as a method of 'opening up' planning processes. There are two different rationales behind public participation in road planning; these are described in the following sections.

8.2.1 The democratic aspect of public participation

Firstly, from a normative viewpoint, the involvement of the public can be based on a stated need to include people affected by the decisions made (refer to e.g. [70]). In line with this, there is emphasis on the democratic right to be involved in public policy processes and the importance of reducing or removing all barriers to such involvement. Hence, it is argued that people living in settlements where noise increases temporarily or permanently in the wake of road projects should be involved in the planning process. These arguments should be heard and opinions should be taken into account before a final decision is made. Typically, in line with this approach, it could further be emphasised that while professional expertise may deduce some societal values and preferences (which are fed into the policy process), their valuation techniques and assumptions can be insufficient. Therefore, from this perspective, professional expertise cannot replace direct public involvement as a means of bridging the gap between values and policy [71]. Public participation is considered a democratic right, not only a means to an end. Therefore, enhanced democracy is emphasised even though this may detract from efficiency. This means that a potential loss in effectiveness is considered acceptable, as it contrasts with what is seen as an undemocratic character of closed, expert-laden planning processes. Thus, public participation is a way of ensuring the overall legitimacy of the road-building process. This is not to say that participation implies complete sharing of decision-making power; rather, it is a recognition of the shared responsibility for both negative and positive aspects of road projects.

8.2.2 Public participation and effectiveness

Secondly, effectiveness and broad involvement are not treated as trade-offs. Instead, involvement of the public is seen as increasing the effectiveness of decision-making processes. This tradition is often linked to concepts like collaborative and communicative planning (see e.g. [72] and [73]). Several arguments are used to support the suggestion that public participation is effective. First, it is seen as providing essential knowledge, not only about the preferences of the public, but also potentially more specific information relating to local knowledge. Accessing such information, which is often unavailable to professional agencies, may illuminate the unintended consequences of the project, thereby helping to avoid inappropriate developments and instead secure better solutions.

It is important to note that involvement with the public does not necessarily mean that noise reduction is maximised, but rather that chances of reaching informed and legitimate decisions are improved. For example, in a Belgian case, involvement with the public actually led to noise reduction measures not being taken [9]. In this instance, the result of involving the local government and inhabitants was that the noise barrier under consideration was not constructed. After investigating the various effects of the barrier on noise and sunlight, etc., the participants decided not to have a barrier built. This illustrates the need to balance the different needs in noise mitigation work, taking the opinion of people affected by decisions into consideration.

The suggestion is that the public holds key resources of knowledge which policy makers and planners need to achieve their goals [71]. This was evident in a Swedish road project where the dialogue with the public was found to considerably improve the planned road by reducing inconvenience, traffic dangers and environmental impact [74]. Furthermore, the process contributed to increasing public acceptance of a given project, leading to another argument as to why public participation is seen to benefit effectiveness. According to Innes and Booher [73], it is easier to reach viable compromises when the public and other relevant stakeholders are involved. Such inclusion leads to lower tension between the parties, eventually facilitating implementation [75]. With this approach, continuous negotiation and involvement with the public, assists in creating improved outcomes. Once again, the importance of involving parties at the early stages of the process is stressed to avoid disagreement further on. Rydin and Pennington [71] argue that by incorporating relevant views and taking more account of the potential for conflict, delays and even fatal breakdowns in the policy process can be prevented.

The distinction between ‘acoustic landscape’ and ‘perceived soundscape’ illustrates how different views on noise amongst professionals and the public can lead to conflicts and difficult road planning. NRAs often present noise impacts in noise maps, based on model calculations, often referred to as the ‘acoustic landscape’. Therefore, compliance in light of defined noise limits is essential. In contrast, a ‘perceived soundscape’ is represented by people who are affected by the noise. This may be different from the acoustic landscape, as it describes sound experienced by people living, for example, in the adjacent areas. Effective planning processes need to take both into account. A given road project may, for example, be within the defined noise limits, but the change in noise before and after could be significant. This can be illustrated by a situation where a new highway is planned in rural areas near a residential area where there was previously no road noise. This change can cause negative reactions to the project amongst the affected groups of people.

As demonstrated, public involvement can both be related to a normative perspective (that affected parties should be included) and an effectiveness perspective (that it eventually enhances decision-making processes). In practice, the two categories are not exclusive, as there are researchers simultaneously emphasising the need for inclusion for normative reasons and presenting this as the most effective approach.

8.3 Examples of public participation

Public participation entails much more than just public hearings. Although there are many different ways to engage the public in road projects, they can all be distinguished by whether the participation is primarily about an agency informing the public of plans (in a top-down manner) or whether the public is actively being involved in the development of plans. Public participation methods are described in the following sections. These methods are in use in a selected set of CEDR countries [9].

8.3.1 Presentation of noise levels

Project owners and local authorities should aim to increase the understanding amongst not only those affected by road noise, but also decision makers and the motorists responsible for the noise. Communication on understanding road noise is an essential part of public involvement as road noise can be presented in several different ways; not all of these are easily understood by the general public.

One approach is to use maps illustrating areas exposed to levels of, for example, 50, 55, 60 and 65dB. Exposed areas can also be presented statistically, e.g. with percentages of houses exposed to levels greater than 60dB (refer to Section 3.4). Furthermore, noise levels can be presented at the street level, exemplified by the use of a mobile noise barometer in Zürich, Switzerland [76]. The device, as illustrated in Figure 8.1, is placed on identified locations on roads for three weeks. Noise from passing vehicles is recorded and immediately presented on a large display. The intention is to illustrate the actual dB level to both pedestrians and motorists.

Figure 8.1: A mobile noise barometer in Zürich, Switzerland [76].

Another method of communicating noise, and where dB are not used in the presentation, is to categorise areas in accordance with their noise exposure or expected noise reduction (refer to Section 3.2). On a map, Zone 1 could describe an area where 10–29% of the dwellers are highly exposed, in Zone 2, 30–59% are exposed, and in Zone 3, above 60% are exposed. In [76] it is illustrated how noise maps can be used to illustrate health effects, e.g. by making a distinction between areas below and above 65dB (the risk of cardiovascular diseases is higher in the latter areas). Lastly, communicating noise could be carried out through listening examples; a method which is further described in the following section.

8.3.2 Public meetings

Public meetings represent a method of involving the public and are often applied in relation to larger road projects. Those affected by a road project can meet with those responsible for its planning and implementation. The affected parties are not only dwellers and house owners experiencing changes due to road projects, but also stakeholder groups such as retailers and estate developers. Important functions of such public meetings are to reduce anxiety, related to lack of knowledge and to create a shared understanding of realistic options to mitigate noise. The latter involves informing the public that even though the official noise guidelines are followed, it will be possible to hear a new road and potentially be annoyed by it (refer to Section 3.2).

There are several factors which need to be dealt with in order for such meetings to actually involve the public. Firstly, there is the question of actual participation. One ongoing challenge, Rydin and Pennington [71] note, has been the apparent difficulty of actually achieving effective participation by all relevant sections of the public. Often, there is partial participation by vocal and well-organised interest groups, while other sections of the population remain non-mobilised. However, a study by Henningsson *et al*. [77] indicates that those living close to road construction sites are most concerned and involved in the planning process.

Figure 8.2: Public meeting about a new road project in Denmark.

One way to encourage people to participate is through improving the dialogue between groups with different opinions and perspectives. However, this involves avoiding a common trap where communication at public meetings becomes one-sided [78]. Another way to involve people at public meetings is to provide examples of different sound types and levels (refer to the following text).

In some cases, working groups could address specific subjects such as the design and location of noise barriers, as well as the design and landscaping of areas and vegetation between roads, noise barriers and residential areas. The working groups could also address the design, landscaping and function of land in relation to an earth noise barrier (refer to Section 4.3.4). This includes more open challenges such as how noise abatement can be developed in a way that also involves structures such as bike shelters, laundry buildings or even a community house for local residents. The members of such working groups could be representatives of stakeholder groups (e.g. owners and tenants associations) or active local people, volunteering to take on the challenge at a public meeting or similar.

Group sessions can also be arranged as workshops and roundtable discussions, involving a mix of representatives of institutions, experts and the affected public.

8.3.3 Exhibitions

Exhibitions can be used to inform the public about noise issues for a longer period of time. These can be organised as 'gallery walks' at public locations such as town halls and public offices. With the use of roll-ups, noise challenges and implemented or planned solutions can be presented in detail, providing the public with an opportunity to gain in-depth knowledge. Exhibitions can be set up after a planning event, e.g. after the completion of a noise action plan, but also in advance to inform the public about a forthcoming planning process. In the latter case, this allows the public to become familiar with the topic prior to the participation process.

Figure 8.3: Exhibition about road noise in Hamburg.

8.3.4 Listening examples

Listening examples provide a method of presenting noise in a comprehensible way to the wider public. Either on the Internet or in public meetings, interactive sound examples can be used to demonstrate noise in different situations. The listening examples could include different types of noise such as road noise, airplane noise and noise from wind turbines. Different levels of noise may be compared, e.g. in the range of 50–70dB, and situations before and after a new road construction could be compared. Comparison could also be used to illustrate the noise effect of higher speed limits, as well as the effect of larger traffic volumes on a given road stretch. Lastly, the effect of different types of noise-reducing measures could be illustrated.

Denmark has had positive experiences with occasionally supplementing noise maps with listening examples at public meetings (refer to Figure 8.3). Through a set of headphones, the participants can listen, for instance, to differences in noise levels in situations with and without noise barriers or with and without noise-reducing pavements. Amongst other procedures, this was used in a series of public meetings in different urban areas along the Copenhagen ring road where the results of the EIA were presented.

Figure 8.4: Participants testing out the listening example at a public meeting in Denmark.

8.3.5 Noise walks and bicycle tours

Noise walks and bicycle tours can be arranged to provide the public with on-site information about a specific noise situation or an expected future challenge (refer to Figure 8.5). Therefore, noise can be discussed in its real-life context. Tours to quiet places or places where noise mitigation has been particularly successful can also be arranged. The on-site character of noise walks and bicycle tours, facilitates the discussion and documentation of positive solutions, as well as interaction between the public and public officials.

Figure 8.5: Noise walk in Osnabrück, Germany.

8.3.6 The Internet

The Internet provides an opportunity to reach a broad population and provide information about noise. The study of a selected set of CEDR countries revealed that informing the public through designated webpages was common practice [9]. The Internet can be used to inform the public through written text, statistics, videos, maps and listening examples. In some cases, the noise maps are interactive, allowing the reader to search for exposure levels in specific areas. For example, in the UK, interactive maps are used to illustrate noise levels (refer to Figure 8.6) and figures are employed to indicate noise exposure (refer to Figure 8.7) in specific geographical areas. Both interactive web maps and listening examples can be used to demonstrate different noise levels and noise situations.

Figure 8.6: Interactive noise level map that can be used by the citizens (source: Department for Environment Food and Rural Affairs, UK).

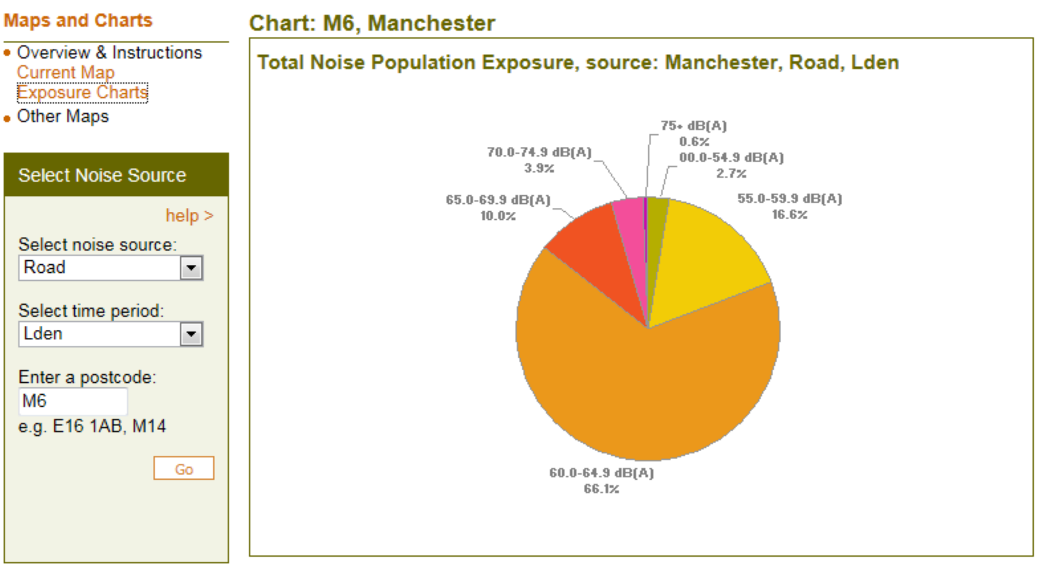

Figure 8.7: Population exposure statistics (source: Department for Environment Food and Rural Affairs, UK).

If a municipality has undertaken noise mapping, sophisticated web maps could allow people to find the noise level at specific housing addresses. The status report of the ON-AIR project [9] also describes how some countries use websites for two-way dialogue, allowing people to post their opinions and complaints, related to existing or planned road structures.

8.3.7 Brochures and local media

Brochures and advertisements in local newspapers are tools used to inform the public about road projects. These communication channels will typically be used to reach a wider public and to describe what road noise is and how different measures can be used to decrease its effects. Brochures and local media could also be used to mobilise the population, e.g. by providing information on legal rights, how to apply for (the implementation and financing of) noise mitigation measures and how to reduce noise in owners' houses (e.g. windows, doors and air ventilation openings).

9 Introduction to interactive examples

The previous chapters described how noise can be handled in different planning stages during the road planning process (Chapter 4), as well as in the maintenance of roads (Chapter 5) and noise action planning (Chapter 7). In addition, various methods for noise impact analysis were presented in Chapter 3.

A series of interactive examples have been developed as a part of the ON-AIR project and can be found on the ON-AIR website (www.on-air.no).

The first part of the interactive examples aims to provide an overview of the various methods which can be used for noise impact analysis. An example of a 'constructed' but not real national road project is illustrated, starting with three variants for comparison.

The user has the choice of three alignments for a new planned road, between the north and the south of the investigated area. The effects of each alignment can be compared using different methods as using simple buffers around the corridors, detailed façade calculations and different spatial types of hotspot analysis.

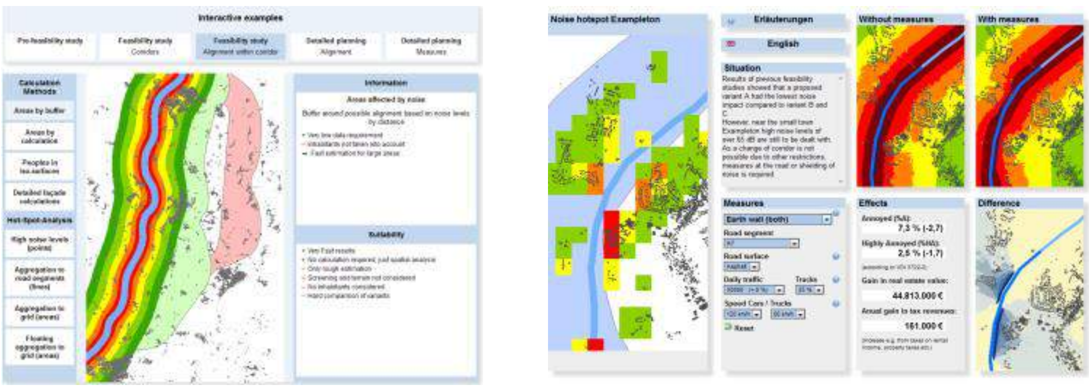

Figure 9.1: Screen shot of interactive examples

The second part of the interactive examples is a tool for comparison of noise mitigation measures. It will quickly predict the results from different noise abatement strategies and present results as both noise maps and statistics on noise exposure. The user can change traffic, speed, pavement type, etc. and choose several variants of noise barriers.

This interactive feature can inform planners how they could evaluate different strategies for noise abatement and select the appropriate measures for noise abatement in given situations. The tool can also be used to facilitate political and public involvement in the actual planning and decision-making process.

10 Conclusions and implementation

This ON-AIR guidance book on the integration of noise considerations as an active factor in all aspects of road planning has been developed on the background of existing experiences and best practices used in various European CEDR member countries. Furthermore, it supports the latest European research and development projects and incorporates the results of the latest CEDR noise projects: DISTANCE, FOREVER and QUESTIM.

One objective has been to include all aspects of road planning and maintenance activities, where active consideration of noise at the correct stage in the planning processes can improve active noise abatement for the benefit of the society's economy.

The guidance book can be seen as a general European collection of effective tools and methods which can be used by road planners and planning teams with different professional skills. The general purpose of the guidance book has been to facilitate road administrations in performing technically optimised and cost-effective noise protection and noise abatement along the main road network in Europe, and therefore improving the living and general health conditions of the many Europeans who live as neighbours to the main road network.

This guidance book can also be seen as an aid in the practical implementation of the objectives of the EIA Directive from the EU, amended in 2014, which includes an increased focus on human health, improved public involvement in the planning processes, and an increased focus on sustainable development and management of the road infrastructure.

The practical implementation of this guidance book can be carried out in at least two different ways. Firstly, the guidance book can be characterised as European in the sense that it does not include the existing planning procedures, practices, legislation guidelines and prediction methods used in all the various European countries. The guidance book can be implemented by being used directly by professionals as inspiration and a toolbox in conjunction with local national procedures, practices, etc.

This guidance book can also be implemented by being 'translated' into the national planning context of individual European countries. This can be achieved by using this guidance book as inspiration and a toolbox when preparing new national handbooks for integration of noise in the planning processes of a given country. It is up to the national practices, economy and environmental management and guidelines to include what is nationally considered relevant at the different planning stages.

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Annex A: Cost-benefit Analysis on Noise

Introduction

Appropriate management of road surfaces is not only economically important, but also essential for preserving desirable properties of road surfaces such as maintenance of friction, drivers' comfort, reduced road–tyre noise emissions, reduced emissions of greenhouse gases and the release of pollutants to atmosphere and water bodies. Good performance on some parameters may reduce road surface performance on others, so the investment, resurfacing and maintenance efforts need to balance different needs according to traffic, road type, built and natural environments and the use of studded tyres.

In this annex, the focus is on economic analyses of road investments, maintenance efforts and roadside measures (traditional and green noise barriers and surface treatments to reduce noise). The type of questions we seek to answer on the economics of investing and maintaining a stretch of road are as follows:

- How do we choose between a more durable but more expensive surface and a less expensive but less durable one?
- When does the additional cost of adding extra noise-abatement elements, using higher quality components with enhanced noise reduction or increasing the size of a noise-reducing structure exceed the additional acoustic benefits?

The types of questions we seek to answer for road pavement production are the following:

- Which combination and quality of materials and/or surface treatments is optimal with respect to satisfying the various and partial conflicting requirements for road surface properties (rolling resistance, road friction, low-noise durability, price and ease of deployment)?
- Which type of road surface is best suited to different contexts (traffic volume, vehicular fleet, neighbourhood, environment, type of road stretch)?

The types of questions we seek to answer for road pavement deployment are as follows:

- What are the savings to motorists and equipment cost per kilometre of reducing the deployment time? Are these higher than the added cost of, for example, paying for more shift work?
- Is it feasible to fine-tune the laying process and pavement properties according to the local situation (e.g. thicker surfaces, surface texturing)?

The types of questions we seek to answer for road system asset maintainers are the following:

- What procedures and/or tools should be used to monitor the status of the road surfaces and generate the required statistics?
- What are the best overall maintenance strategies for road surfaces with different maintenance histories and requiring different rates of repair, resurfacing and other efforts?
- Which competing worthwhile maintenance activities for road stretches with different levels of importance and priority and in different stages of disrepair should be funded and which should not?
- What is the information needed for providing decision-making support and making sound decisions?

Ideally, one should be able to lay road surface pavements using production techniques and deployment machinery/procedures, allowing properties to be fine-tuned according to traffic and the environmental situation. Traffic flow parameters (volume of passenger cars and heavy vehicles, lane usage, driver behaviour and speed of traffic) and the environment (roadside environment, vegetation, distance to residential areas, layout of building blocks/structure including the vertical dimension – number of floors), vertical distance to affected blocks/dwellings, number of people currently affected and in the future are all important.

The type of road surface, resurfacing activities and maintenance should strive for a property mix suited for the particular traffic and environmental contexts of the stretch of road being treated. This could, in theory, enable a seamless application of more expensive solutions, producing higher noise reductions close to residential areas, increasing friction in acceleration/deceleration areas and, whilst adhering to safety standards, prioritising lower rolling resistance on stretches where other concerns are of lesser importance.

The next best solution is to select a road surface to match the main features of the local situation. As each stretch of road is part of a road network expected to satisfy minimum standards and have uniform and predictable properties, there are limits to how far local optimisation can be pushed.

Road-surface replacement and/or maintenance strategies may be part of overall transportation and/or environmental packages intended to achieve transportation and/or environmental goals modifying some of the requirements. Changing speed limits and the vehicle mix, enforcing noise-emission regulation and/or using noise barriers may therefore supplement road surface investment and maintenance strategies. In contrast, increases in traffic or in evening and night-time traffic may augment the environmental load over time, thereby putting more pressure on road managers to optimise their efforts.

Cost effectiveness and cost-benefit analysis

Principles of cost effectiveness and cost-benefit analysis (CBA) are as follows [79]:

- The impacts of a scheme should be based on the difference between forecasts of the without-scheme and with-scheme cases;
- Impacts should be assessed over a defined appraisal period, capturing the planned period of scheme development and implementation and typically ending 60 years after the scheme opening;
- The magnitude of impacts should be interpolated and extrapolated over the appraisal period, drawing on forecasts for at least two future years;
- Values placed on impacts should relate to the perceived costs, factor costs and market prices unit of account, converted as appropriate from factor costs using the indirect tax correction factor;
- Values should be in real prices, in the relevant department's base year, accounting for the effects of inflation;
- Streams of costs and benefits should be given in present values, discounted to the relevant department's base year;
- Results should be presented in the appropriate CBA metrics, typically a benefit-cost ratio (BCR); and
- Sensitivity testing should be undertaken to reflect uncertainty.

Economic analyses thus take into account that projects have different time profiles, and that costs and benefits which come late in the planning period are more heavily discounted. Increasing the durability of a road surface, thereby increasing its lifetime, thus has two beneficial effects, as follows:

- The production and road surface laying costs per year are reduced; and
- Each resurfacing investment is discounted more heavily, as it is pushed further into the future.

Typically, investments are made up-front, after which there is a period of maintenance, resurfacing and the end of the useful lifetime. The major expenditures are made before the road is opened. Annual benefits are generally much smaller than the investments, but they are delivered year after year. Their accumulated worth thus needs to be calculated.

Different European countries apply slightly different accounting principles. They differ with respect to the number of years a project is evaluated over, the rate of discounting, whether use of public funding should be associated with taxation cost (i.e. depriving citizens of funds deprives them of other goods/opportunities), how to deal with VAT (value added taxes), fuel tariffs, costs before or after taxation, etc. There could also be differences in the planning horizon and how residual values are dealt with i.e. the value of investments at the end of project period, but where the infrastructure elements may still be considered to be of value.

For projects in a single country, the national calculation regime should be applied. For EC-wide analyses and comparisons between countries, a common calculation framework needs to be selected.

In a project on green noise abatement measures [80], valuations from a project encompassing several European countries were employed [81]. In addition, the aesthetic/amenity values of tree belts and parks which could be important for the assessment of green noise abatement measures were derived from international studies.

It should be noted that socioeconomic analyses differ from simple calculations of cost in that it is the societal cost that is important. If a country imposes a fuel tax simply to generate income, the taxation part of the fuel price is not considered a societal cost; it is merely a change in ownership of the money and the society as a whole is considered to be as well off after the transaction as before. In some situations, land may be transferred from local authorities to public road authorities or vice versa. The societal costs are not the transaction price, as who owns the land is irrelevant to the societal value of the property. However, the opportunity cost is important; since the land is claimed for road purposes, it may no longer be employed otherwise.

Cost-effectiveness analysis

Cost-effectiveness analysis (CEA) favours the least costly measure or group of measures achieving a predefined acoustic goal, e.g. a 3dB noise reduction. Measures which have a more efficient design, employ fewer or cheaper materials or cost less per dB of noise reduction achieved for the affected population are favourable. A disadvantage of CEAs is that they disregard other potentially important positive or negative effects of the measures.

An advantage of a CEA is that there is no need to place a monetary value on the acoustic target, so it can be used in situations in which the monetary value of the benefits has not yet been assessed through valuation studies. This is currently the case for acoustic improvements in most non-residential settings, such as bicycle and pedestrian paths, city centres, cultural heritage and recreational areas. Knowledge is lacking on how frequently such areas are used, the duration of each visit/activity and the relationship between noise exposure and effects on human perception, well-being and health.

CEA is often sufficient in situations in which a predefined environmental limit needs to be reached or a political decision has been made to the effect that a given acoustical improvement should be attained.

CEA may also be used to make a selection from a portfolio of potential measures and contexts. Given a fixed budget earmarked for noise control purposes, it is possible to use CEA to seek out context/measure combinations which provide the highest acoustic benefits per unit cost. One starts by employing those measures and contexts which produce the highest noise reductions per Euro. After exhausting the opportunities for using the best measure/context combination, if there are funds left, one proceeds with the second best measure/context combination until the funds are used up.

Where different projects provide cumulative benefits such as the number of people highly annoyed or a National Noise Annoyance Index, CEA can be used to select policies/strategies or projects providing the highest reduction in this number per Euro spent. An example would be to achieve the highest reduction in the number of highly annoyed persons for a given budget of, e.g. €100 million.

This noise-reduction policy differs from a regulative approach in that it selects areas and locations which have a suitable fit to the available measures and ignores areas where the context is unfavourable. The policy is more efficient than a regulative approach. At the same time, it may appear unfair that it treats people exposed to the same environmental externalities differently.

One could perhaps argue that a regulative approach is best when dealing with unacceptable situations below minimum standards, whereas an economic approach could be preferable when dealing with improvements above minimum standards. However, to strike a balance between economic rationality and environmental justice, different facets may need to be considered, and this represents a political decision.

Cost-benefit analysis

CBA takes a more holistic approach than CEA, expanding the scope of analysis to all impacts for those affected by the measure. Road surfaces have many properties, each of which can be assigned a value. The objective of the CBA is to achieve the best overall performance in monetary terms, versus the cost.

The CBA approach is more demanding than CEA because all relevant effects need to be assigned a monetary value. When such assignments are available, the cost efficiency of a noise-reduction method can be calculated. It should be noted that efficiency is different from effectiveness.

Figure A.1: The results of a CBA are often expressed in the form of a Benefit to Cost Ratio (BCR). Values above one (BCR >1) are cost efficient. However, to be competitive, projects should be robustly efficient (BCR >2).

A measure should have **high** socioeconomic efficiency (large benefits vs. costs), whereas the cost effectiveness of a measure should ideally be **low** (cost per achieved unit of improvement).

When considering the cost efficiency of a project, we are interested in the full set of effects. We want to maximise the sum benefits relative to the sum costs. In some cases, a noise-reduction measure can produce multiple benefits and their accumulated worth improves the social efficiency of the project. In others, for example, where a noise screen destroys the visual aesthetics of a landscape, separates one part of a community from another or acts as a noise reflector (if an absorbing barrier is not used instead) resulting in negative effects of other groups of people, the overall benefits are reduced.

Revealed and stated preference studies

Revealed preference studies, such as the hedonic pricing method, are often used to assess the monetary value of local public goods. In the hedonic pricing approach, the price differential when purchasing or renting houses or apartments with various properties, such as the acoustic environment, urban greenery, access to public transport, etc. is analysed.

Hedonic pricing studies need to take into account all housing characteristics which are likely to affect the selling price (size, building quality, number of bathrooms, etc.). Based on hedonic-pricing methodology, statistical techniques are used to extract the relative importance of, for example, acoustical quality, vibrations and aesthetics for the valuations. However, the value of such regression analyses depends on the availability of suitable indicators, a sufficient number of dwellings (respondents) and sites. Whilst several studies provide unit values for reducing noise by 1dB, valuation of other factors may be scarce or lacking.

An alternative economic assessment to hedonic pricing is the stated preference approach. For this approach, people are asked how much they value different aspects of their environment. One popular method for eliciting such valuations is by choice experiments. In these experiments, people are presented with choice alternatives where the attributes of alternatives are systematically chosen, allowing statistical analyses of which factors play the greatest roles. This stated choice methodology has the advantage that it is easier to extract valuations of particular aspects of an environment, such as its perceived restorative properties, for example, by incorporating one or two relevant 'willingness to pay' questions in socio-acoustic or soundscape research efforts already employing questionnaires.

In most cases, the stated preference methodology is based on extracting individuals' willingness to pay from their own funds for an improvement in quality to the benefit of the general public.

One possible type of question could elicit the respondents' use of municipal or state funds for increased/decreased availability of restorative areas, changes in how much time is spent or the size of entrance fee deemed acceptable. The extracted values are often given as population averages. When applying the values, it may be useful to consider subpopulations and contextual factors. Noise-sensitive persons may perceive noisy areas to be considerably more annoying than non-sensitive persons.

For noise-control measures, the economic values of noise reductions are determined by applying unit prices, for example, for the value of given dB reduction, multiplied by the number of affected persons/dwellings. When noise-control measures also have non-acoustic effects, these should also be assessed in economic terms. The expanded scope of CBA may favour more expensive noise-reduction methods than are allowed in a CEA. If measures are aesthetically pleasing, the cost of green barriers or vegetation for noise protection can become subsidised by the contribution from the value bestowed on recipients of aesthetic improvements or other additional benefits [82].

If the benefits exceed the costs, the BCR exceeds one (BCR >1). To be competitive relative to other projects wishing for public funding, a noise-reduction project should preferably be robustly efficient, i.e. the benefits should outweigh the costs by a factor of two (BCR >2).

Generally, uncertainties are associated with both the cost and benefit estimates. Factors and aspects which have not been assigned a monetary value, or for which the monetary value is deemed uncertain, should be reported separately. We should also bear in mind that the costs of the measures are often dependent on the local availability of materials, scarcity of labour and strength of the competition. Occasionally, there are larger uncertainties associated with 'hard' cost estimates than the 'soft' benefit estimates.

Noise control and soundscape approaches

The traditional noise control approach focusses on areas exceeding certain noise levels using regulation (noise zones, limits and guidelines) and financial disincentives (polluter pays) to limit adverse effects on life quality and health. However, one should be aware of the emergence of an additional socio-political and economic rationale in urban areas.

Promoters of the soundscape approach focus on the value of positive urban environments in attracting people, businesses and economic activity. The idea is that it is not sufficient to limit how bad an area is allowed to become. Politicians and city and road planners need to foster positive urban qualities of areas to attract skilled labour, high-income businesses, tourists, etc.

When cities are successful in creating a positive urban environment, they will gain a higher number of businesses which generate tax income and prosperity. If neighbouring cities do not want to lose their businesses to such cities, they will need to implement changes. These aspects are relevant for roads passing through or bordering urban areas which have high value due to their economic, cultural or recreational attributes. One challenge is that valuations of soundscape quality of public areas which provide cultural heritage values, value added for business environments and businesses who have pedestrians making use of public areas as their customers, have received little attention and the valuation is not clear. There is also no accepted indicator for the health-promoting restorative properties of relatively quiet areas; therefore, it is difficult to assess the potential benefits of having access to such an area. The value of quieter areas is probably more dependent on the context, as it depends on the relative scarcity or abundance of areas that are similar in attributes and/or whether there are suitable indoor quiet areas for recreation.

Annex B: Methods for noise evaluation

Valuations of noise benefits

In practice, noise-reduction benefits are assigned a unit value; the size of which depends on the effects that are valued, the methodology used and state of knowledge. When using a unit value, one assigns an average value to the noise reduction of 1dB for each person. In some approaches, the value of the noise reduction is assessed through the impact reduction in the form of the reduced number of people that are highly annoyed, moderately annoyed or affected. In other approaches, the underlying rationale for the valuation is both life quality aspects (noise annoyance) and health effects.

Traditionally, noise annoyance has been assessed through the number of people who are highly annoyed [83]. Socio-environmental studies typically indicate that the number of people who become highly annoyed, increases more rapidly when the noise levels increase (refer to Figure B.1).

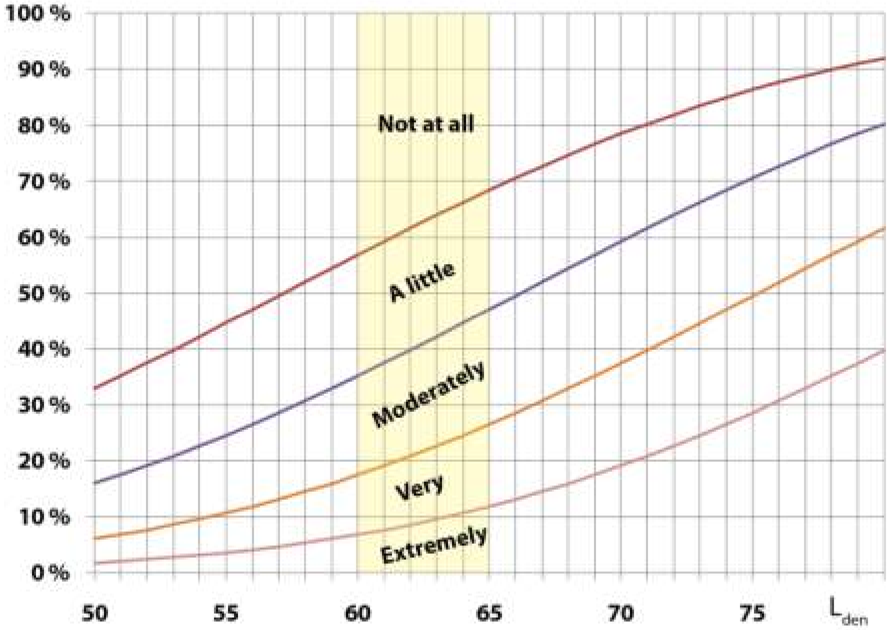


Figure B.1 Exposure–effect relationships (based on [84])

This means that a noise reduction from 70 to 69dB should be valued higher than one from 55 to 54dB, because the reduction in the number of highly annoyed people is greater at higher noise levels (steeper slope). Norwegian authorities use €1,548 per highly annoyed person per year in 2011 values. The number of highly annoyed persons is calculated with the VSTØY programme [85]. When using other calculation tools, the valuation is based on dB, and a value of €34.30 per person per dB per year is used (2011 value).

However, it is not only the steepness of the slope that matters, but also the number of people who benefit. Most people live in dwellings with low noise levels. This means that noise reductions at lower noise levels often benefit more people (refer to Figure B.2).

An annoyance score for each degree of annoyance can be determined from the number of scale points. The scale points are translated into a number between 0 and 100. One can then use linear regression to estimate the average annoyance score for a given noise level (refer to Figure B.3).

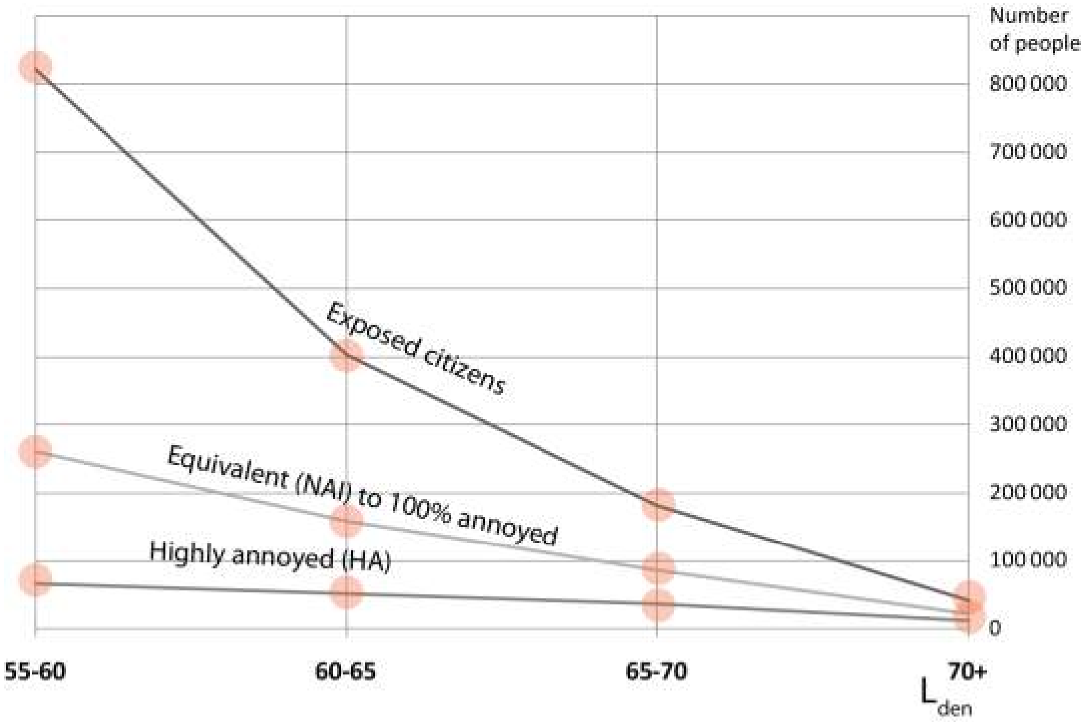


Figure B.2 Number of people affected, 'annoyed' (as indicated by the number of highly annoyed persons) and highly annoyed in Norway by equivalent road traffic noise exposure (L_{den}) [86].

The equivalent number of highly annoyed persons (NAI) is derived from exposure–effect relationships. Each annoyance category is assigned a score, and the average annoyance at a given noise level calculated. For road traffic noise the relationship is:

Average annoyance score = 1.55 %*(L_{den}-37). Refer to Figure B.3.

To calculate total annoyance in a country, the number of people exposed at each noise interval is multiplied by the annoyance score for the interval. An example is as follows: We have 20 persons exposed to 50dB and 10 persons exposed to 69dB.

At an equivalent noise level (L_{den}) of 50dB, the average annoyance is 20%, and if 20 persons are exposed to this noise level, the NAI is calculated as 20*20% = 4. If, in addition, 10 persons are exposed to 69dB with an annoyance score of approximately 50%, then the NAI increases by 5 and we get the result NAI=4+5=9.

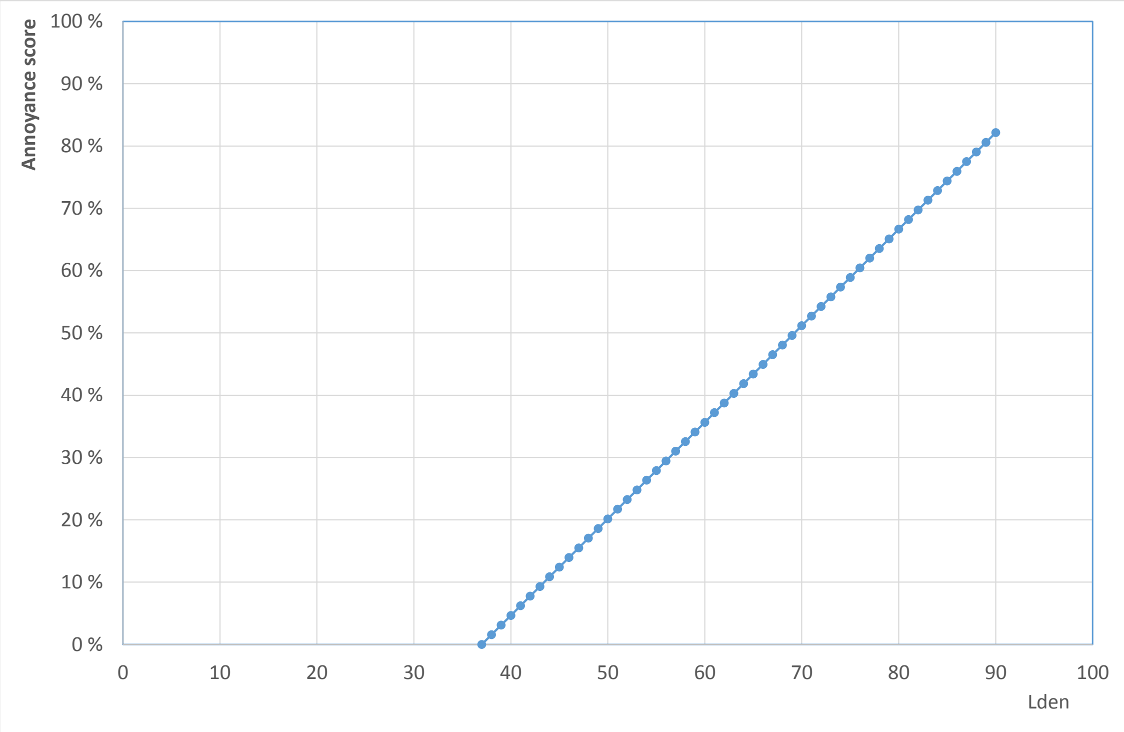


Figure B.3: Average annoyance score as a function of noise exposure (L_{den}) in dB.

Not only amenity effects but also the health effects of noise are thought to increase at high noise levels (typically above 60–65dB). In the HEATCO (Developing Harmonised European Approaches for Transport Costing and Project Assessment) project [87], noise costs were derived from country-specific valuations.

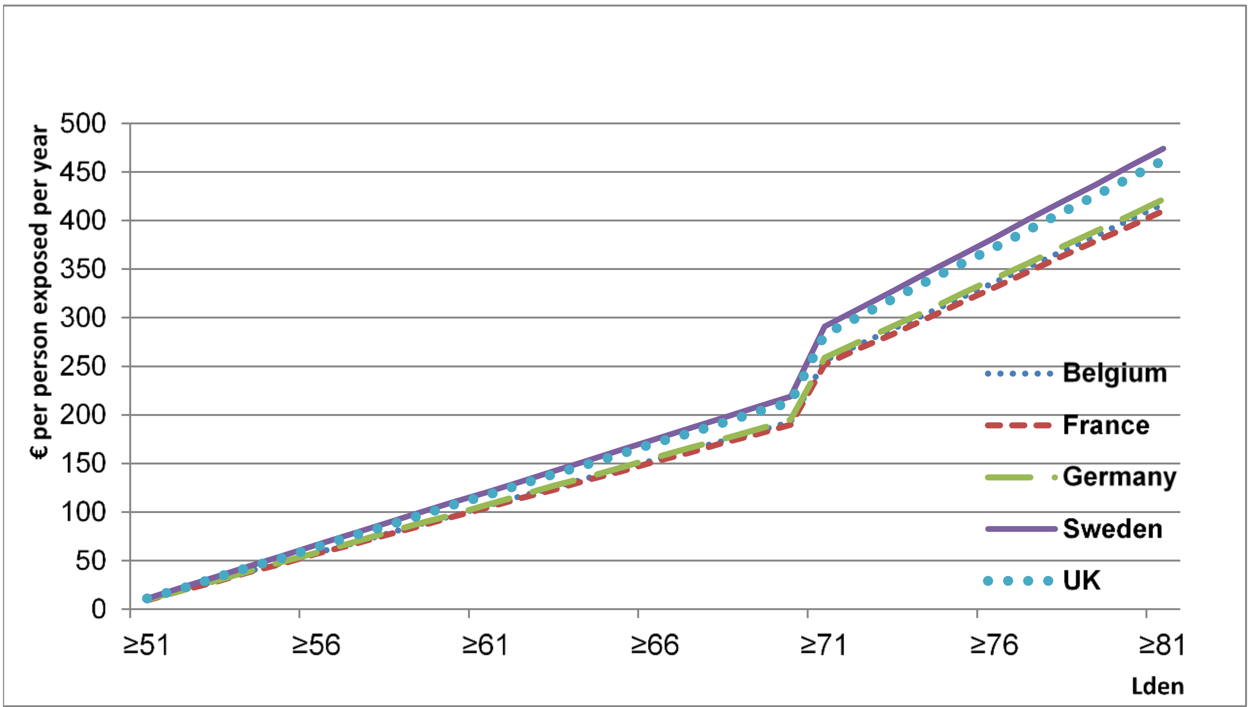


Figure B.4: Noise cost per dB above a cut-off value of 50dB [81].

Two ranges were defined: 50–70dB (annoyance) and 71dB and over (annoyance + health – myocardial infarction). The effect of a measure is calculated as the noise after (i.e. post mitigation) minus noise before (i.e. pre-mitigation) the measure; for example, if the noise (in a Swedish case) is reduced from 71 to 66dB for 100 people, the benefit can be calculated as (250-160)*€100 = €9,000. The second range, which takes health effects into account, has a steeper slope.

The reporting of these results is less than clear, and there could be a better discussion on how the new results compare to those obtained using hedonic pricing methods [87]. Figure B.4 could be considered misleading in that it is not obvious that it is intended to be used with a weighting factor, i.e. the proportion of people who are annoyed [81].

Assessments differ between countries

Amongst European countries, a wide variety of methods exist for evaluating noise exposure. A main distinction between different methods is the requirement for a 'limit value' or the use of dose–response relations based, for example, on noise annoyance.

Some methods, such as the German LKZ ('LärmKennZiffer', 'noise index') [88] are based on the exceedance of a freely selectable limit value. The LKZ, for example, is the exceedance of a limit value in dB, multiplied by the number of people affected, without taking the annoyance itself into account. It provides a simple and explainable approach.

Other methods which focus on noise annoyance as 'highly annoyed', allow no choice in limit values themselves. As noise annoyance occurs even with comparably low noise levels, hotspot identification requires a comparison of noise loads for given areas. An absolute identifier is not feasible.

Most methods taking noise annoyance into account, such as the German VDI 3722-2 [89], are based on several earlier reports regarding noise annoyance (as from Miedema, Vos, Guski and others). In general, two indicators are frequently used to describe noise annoyance: 'highly annoyed' (% HA) and 'sleep disturbance' (% SD). The percentage of people affected is calculated based on the noise levels.

Various documents provide methods for calculating these indicators, such as the 'Good practice guide on noise exposure and potential health effects', published by the EEA (European Environmental Agency) in 2010 [90] or the 'Night noise guidelines for Europe' published by the World Health Organization (WHO) in 2009 [17].

For example, the percentage of people 'highly annoyed' according to the VDI 3722-2 is calculated by this formula where $L_{r,TAN}$ is equal to the L_{den}:

Road traffic (42dB ≤ $L_{r,TAN}$ ≤ 75dB)	$\% HA = 9{,}868 * 10^{-4} (L_{r,TAN} - 42)^3 - 1{,}436 * 10^{-2} (L_{r,TAN} - 42)^2 + 0{,}5118 (L_{r,TAN} - 42)$

The VDI 3722-2 also 'proposes procedures to determine characteristics for evaluating in case of impact of different types of noise sources with regard to annoyance and self-reported sleep disturbance.' These procedures comprise 'a method to estimate the total annoyance based on effect equivalent continuous sound pressure levels from different types of sources'. The road traffic is 'selected basically as the reference quantity for effects'. Chapter 6 of the VDI provides a procedure for investigating the effect of noise-abatement measures and planning alternatives.

The Danish values are expressed as DKK per Noise Exposure Factor (NEF) [91]. The NEF is a unit used in Danish social cost calculations in relation to noise. NEF expresses the total nuisances in a defined geographical area and is calculated as a sum by weighing of households exposed to different noise levels. The weighting factor follows an exponential curve and is calculated from the following formula: Weighing Factor = $0.01 * 4.22^{(0.1(L_{den}-44))}$. The exponential curve used is illustrated in Figure B.5.

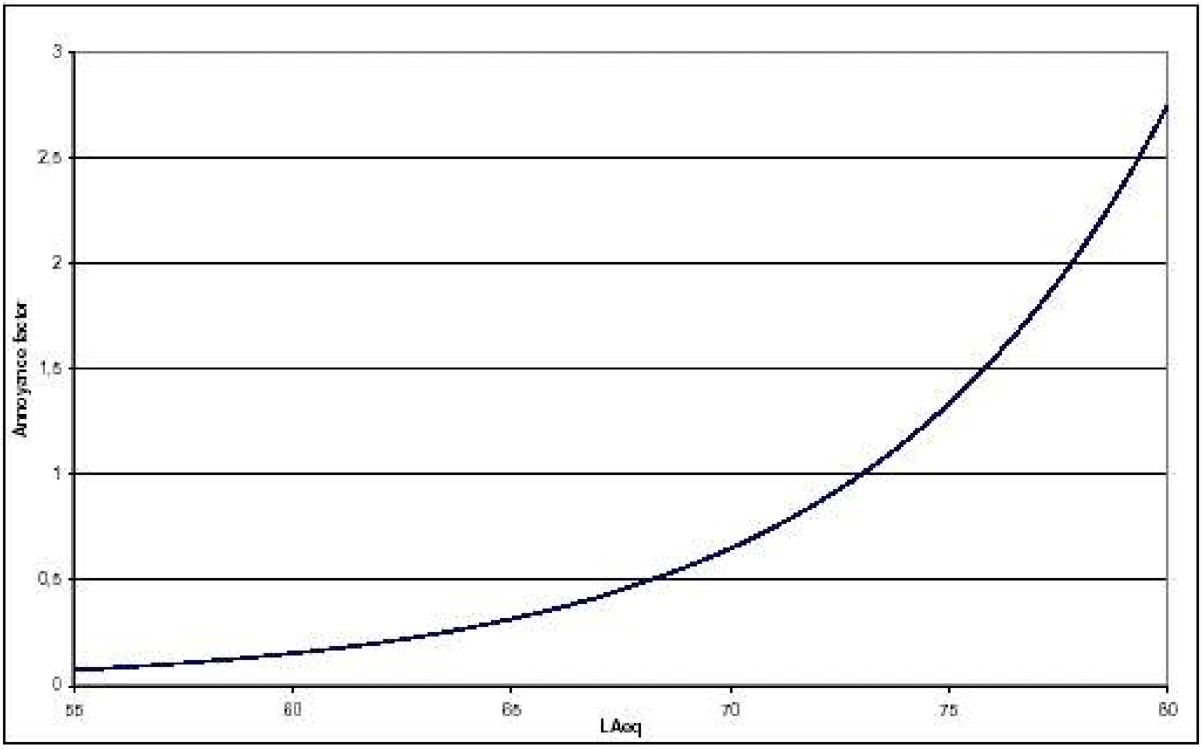


Figure B.5: The exponential curve used for weighing factors in the Danish system, expressed in relation to L_{Aeq}.

After converting to Euro, the Danish value corresponds to €32 per person-dB per year, which is considerably higher than the unit value suggested by the EU working group.

Current valuations of road traffic noise in Sweden take both life quality (annoyance) and health considerations into account. The new values are based on a hedonic pricing study [92], where the benefit of a noise reduction is considered higher than in Bickel [81]. The table was later updated to 2010 values (refer to Table B.1).

Separate values are provided for the reduction of outdoor and indoor noise. As at-source measures such as low noise surfaces provide both outdoor and indoor benefits, the total (outdoor + indoor) benefits can be calculated. For these calculations, an average noise insulation of 25dB is used. For windows/façade insulation, the indoor benefits of noise reduction are taken into account. It should be noted that the valuation is per person and not per household. The average number of persons in households varies (in the Hosanna project, 2.4 persons per household was used as a European average.) The benefit of a noise reduction per person per year increases depending on the baseline noise level.

Table B.1: The cost of being disturbed by noise and suffering from health effects from road traffic, SEK2010 per person. Noise measured in L_{AEq24h} (source: http://www.trafikverket.se/contentassets/13c6f625c3324bc4b34a59c9f4594703/20_english_summary_a52.pdf).

Level of noise outdoors	Total cost of noise, indoors and outdoors	Cost of noise outdoors	Cost of noise indoors (at 27 dBA lower level of noise than outdoors)	Level of noise inside the house, given 27 dBA lower level inside the house
45	0	0	0	18
46	276	276	0	19
47	560	560	0	20
48	854	854	0	21
49	1 157	1 157	0	22
50	1 469	1 469	0	23
51	1 798	1 798	0	24
52	2 140	2 140	0	25
53	2 629	2 501	184	26
54	3 146	2 885	374	27
55	3 694	3 296	569	28
56	4 278	3 738	771	29
57	4 891	4 205	979	30
58	5 612	4 718	1 194	31
59	6 395	5 285	1 430	32
60	7 208	5 887	1 661	33
61	8 065	6 526	1 917	34
62	8 956	7 234	2 208	35
63	9 958	8 085	2 492	36
64	11 057	9 031	2 804	37
65	12 182	10 046	3 145	38
66	13 391	11 173	3 523	39
67	14 650	12 422	3 925	40
68	16 068	13 851	4 351	41
69	17 631	15 383	4 823	42
70	19 321	17 024	5 390	43
71	21 182	18 778	6 021	44
72	23 365	20 649	6 698	45
73	25 694	22 645	7 449	46
74	28 176	24 766	8 282	47
75	30 842	27 023	9 234	48

Average noise insulation 25dB

Outdoor vs. indoor weight 60/40

Average noise insulation 25dB

Outdoor vs. indoor weight 60/40

In the United Kingdom's (UK's) [79] approach, amenity and noise annoyance values are added to the independently derived health values of an increase or decrease of 1dB. These vary depending on the noise level.

The disability-adjusted life-year (DALY) method, provided by WHO, calculate[s] the burden of disease, based on exposure–response relationship, exposure distribution, background prevalence of disease and disability weights of the outcome. The excess noise annoyance, sleep disturbances, mortality and morbidity due to living in a noisy environment are assessed and accumulated in one indicator. After assigning a monetary value to one DALY, the results can be converted to monetary terms. However, assigning such a monetary value raises a number of difficult questions concerning the value of life, i.e. whether a life in one country is worth the same as in another, etc.

When taking health effects into account, as in the UK, the value of reducing noise at high levels with 1dB increases – which means that economic calculations will indicate that projects focussing on reducing high-noise situations, ceteris paribus, will 'pay more' than reducing noise levels in medium and low-level situations. The values in Table B.2 use the UK noise indicator $L_{Aeq,18h}$, opposed to L_{den}.

Table B.2: Values per household per dB per year of changes in noise exposure used in the United Kingdom [93]

Volume (L_{Aeq}, 18hr dB)	Kolonne1	£ per household per dB change (per year, 2010 price	Kolonne2	Kolonne3
Low [dB]	High [dB]	Amenity	Health)	Total
55	56	£34.80	£0.00	£34.80
56	57	£37.40	£0.48	£37.88
57	58	£40.00	£2.70	£42.70
58	59	£42.70	£4.16	£46.86
59	60	£45.30	£5.67	£50.97
60	61	£48.00	£7.22	£55.22
61	62	£50.60	£8.82	£59.42
62	63	£53.20	£10.47	£63.67
63	64	£55.90	£12.17	£68.07
64	65	£58.50	£13.92	£72.42
65	66	£61.10	£15.71	£76.81
66	67	£63.80	£17.56	£81.36
67	68	£66.40	£19.45	£85.85
68	69	£69.00	£21.39	£90.39
69	70	£71.70	£23.37	£95.07
70	71	£74.30	£25.41	£99.71
71	72	£76.90	£27.49	£104.39
72	73	£79.60	£29.62	£109.22
73	74	£82.20	£31.81	£114.01
74	75	£84.90	£34.03	£118.93
75	76	£87.50	£36.31	£123.81
76	77	£90.10	£38.64	£128.74
77	78	£92.80	£41.01	£133.81
78	79	£95.40	£43.43	£138.83
79	80	£98.00	£45.90	£143.90
80	81	£98.00	£48.42	£146.42

The Norwegian Noise Annoyance Index is an alternative approach, using the mean annoyance score. Using this approach, one not only counts the number of persons who are highly annoyed, but also those who are annoyed and slightly annoyed. Being ‘highly annoyed’ receives an annoyance score that is higher than if a person is merely ‘annoyed’. The method has the advantage that it takes into account the benefits of noise reductions for those in the population who are exposed to ‘normal’ noise levels. It has also the advantage that the mean annoyance score is approximately linear in shape.

The linearity simplifies the calculation of noise benefits, as all noise reductions (above the cut-off) are treated as equal, irrespective of the baseline level. A counterargument is that the long-term damages are thought to be greater at higher noise levels. With the widespread availability of computers and their ability to undertake a significant number of calculations in a relatively short time period, the argument for the linear approach simplifying calculations is no longer as strong.

The NoiseScore (NS) [94] is based on a function which linearly depends on the noise level L_{den}. Its increase is lower when under 65dB than above 65dB. The value derived from the function is multiplied by the number of affected parties. As the function does not have a lower limit within its range of validity, the calculations are conducted for all level areas. Therefore, affected individuals with loads up to 65dB have less bearing with respect to the result than those who experience levels that are higher than 65dB.

The noise inhabitant level UCE_{DEN} [95] is based on the logarithmic product from the de-logarithmised L_{den} and the number of affected parties. Therefore, this process differs from the other methods which link the L_{den} and the number of affected parties. In contrast to the results generated by other methods, significant effort is required to sum up the UCE_{DEN} values determined in that way (for example, to hectare or building values).

The Bavarian noise evaluation measure (P-Score; Federal Ministry of Transport 1997) is derived from a noise level, a threshold value and the number of affected parties. The evaluation method and the appropriate threshold value can be applied in different ways, depending on the task. In this function, values are only determined when above a threshold which can be selected randomly.

In Denmark, the NEF is the basis of all CBAs of noise from road and rail traffic; ‘[i]t is an expression of the accumulated noise load on all the dwellings in an area. It is calculated as the sum of the weighted noise loads on the individual dwellings in the area, so that dwellings with high noise levels weigh more than dwellings with less noise’. In the Danish approach, the value of noise reduction thus increases exponentially with the noise level [96].

Annex C: Examples of successful noise management and abatement

As a practical supplement to the handbook, this Annex contains more than 30 practical examples of tools of noise abatement and noise management. The examples have been selected as an illustration of the wide variety available in practical noise abatement, implemented in projects throughout Europe and other countries in the world.

The examples have been selected according to the criterion that they could generally provide inspiration to road administrations in Europe, as well as to consultants working on road projects and the general public. Examples may not always be directly copied; it may be necessary to take local conditions and practices into consideration. The collection of examples is inspired by the knowledge of the members of the ON-AIR project team. To some extent, the examples originate from Norway, Denmark and Germany, but a series of examples from other countries is also included.

The examples include the following:

Noise barriers

Example 007 - Noise barriers and screens
Example 024 - Buildings as barriers
Example 025 - Concrete noise barriers
Example 026 - Green noise barriers
Example 027 - Noise barrier with two sides
Example 028 - Tall barrier as sculpture
Example 029 - Transparent noise barriers
Example 030 - Large steel barrier Vienna
Example 031 - Graffiti free noise barriers
Example 033 - Absorbing barriers

Partial or total covering of the road

Example 010 - Tunnel in Hamburg
Example 021 - Tunnel in Oslo
Example 023 - Melbourne noise tube

Measures at the house

Example 001 - HafenCity-Fenster
Example 002 - Noise insolation sliding panels
Example 003 - Fixed glazing in front of the windows
Example 004 - Glazing of balconies
Example 005 - Noise protection building blocks
Example 008 - Facade improvement-Double façade

Example 009 - Facade improvement-Louvred façade
Example 019 - Noise reduction through green façades
Example 032 - Green noise
Example 034 - Grants for facade insulation

Measures regarding traffic

Example 011 - Speed limit of 30km/h on major roads
Example 012 - BLANK
Example 015 - Traffic bans for certain types of vehicles

Combination of measures

Example 013 - Solar energy and highway – Tunnels
Example 014 - BLANK
Example 022 - Three measures at Husqvarna
Example 035 - Ring road Copenhagen

Examples of planning

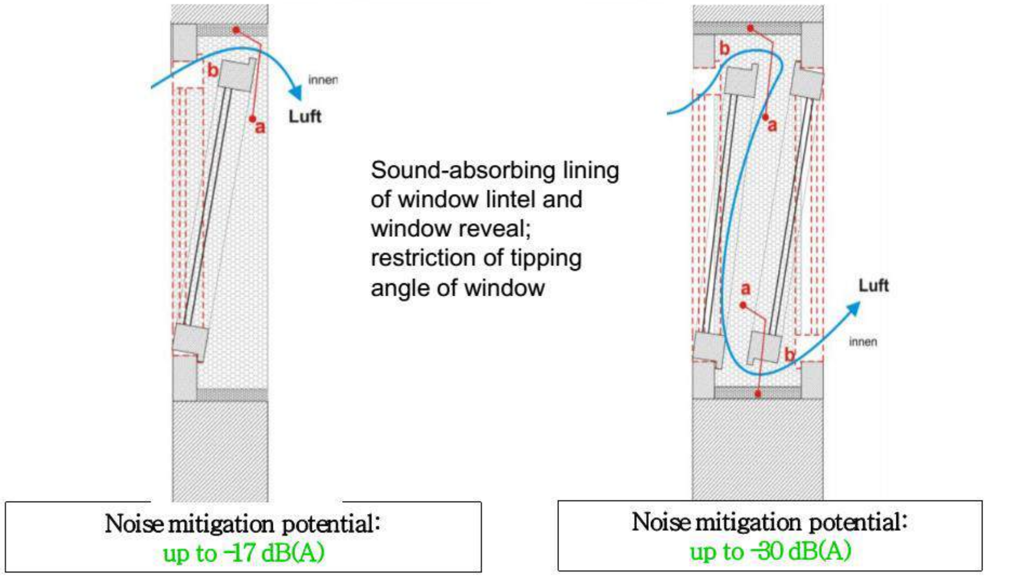
Example 006 - Buildings as Noise Shield
Example 016 - Detail planning ‘Cherbourger Street’
Example 017 - Handling of noise in a policy package
Example 018 - Relocation ‘Wilhelmsburger Reichsstraße’ Hamburg
Example 020 - Handling of noise through planning zones

‘HafenCity Fenster’ – Sound insulation in a partially open window (Example 001)

‘HafenCity’ windows are made from two window layers which are combined with a small gap between them. The space between windows is lined with absorbing materials in order to increase the sound insulation of the window construction. The surfaces of both windows are divided by the special ventilation openings. These can be vertically shifted and are usually placed on the bottom of the inner window and on top of the outer window. Together with the absorbing material, these windows allow sound reduction of up to 30dB, allowing residents to sleep well next to the partly opened window.

Source: Lärmkontor GmbH

Built-in ‘HafenCity’ windows



Source: Lärmkontor GmbH

Design and noise mitigation potential of single (left) and double (right) ‘HafenCity’ windows

Example

In the developing phase of Europe’s largest inner-city development project – HafenCity Hamburg – high noise levels at night (originating from commercial activities in Hamburg harbour) presented the biggest obstacle in achieving the required acoustical standards in planned dwellings. To address this problem, a new type of sound insulation window, more commonly known as the ‘HafenCity Fenster’, has been developed.

The new ‘HafenCity’ sound insulation concept is focussed on reaching interior noise levels of 30dBA in bedrooms with partly opened windows at night time.

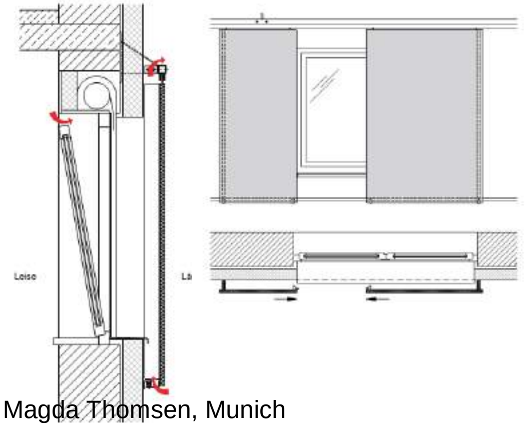
Further information:

http://on-air.no/examples - Example 1

Façade improvement: noise-insulating sliding panels (Example 002)

Sliding shutters made of aluminium panels and mineral wool which is sandwiched in the aluminium frame are used as soundproofing elements in front of the bedroom windows. The sliding panels run smoothly on guide rails and can be closed from the inside. Above and below are the ventilation openings.
Noise reduction is achieved as follows:
External noise levels are reduced following absorption by the mineral wool. In conjunction with the window glazing, noise levels experienced within bedrooms are significantly reduced. The panels darken the bedrooms at night and reduce the sound exposure.
The sliding panels reduce noise by up to 27dB and improve residents' quality of living considerably.

Sliding panel detail, Middle Ring Munich



Source: Magda Thomsen, Munich

Design of the sliding panels

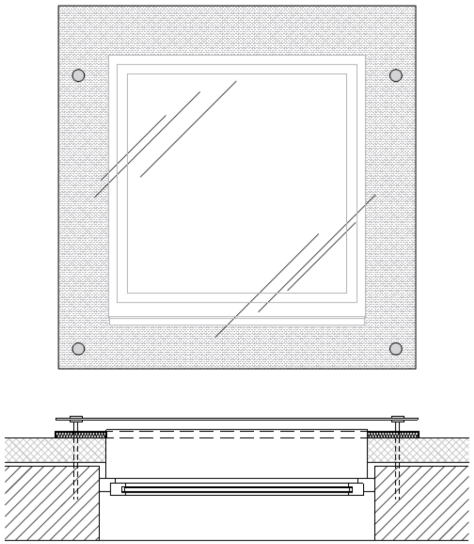
Example
The Middle Ring is one of the main arteries of the city of Munich. Approximately 64,000 vehicles travel daily on the Innsbruck Ring. In the absence of remedial measures, noise emissions associated with this traffic volume can result in a poor acoustic environment for residents.
In order to improve the quality of living in 'Mittlerer Ring', the noise-protection concept was developed. This concept consists of four individual constructions, as follows:

- Noise-insulating sliding panels;
- Fixed glazing in front of the windows *(refer to example no. 003)*;
- Glazing of balconies – Westplatz in Leipzig *(refer to example no. 004)*; and
- Noise protection building blocks *(refer to example no. 005).*

Further information:
http://on-air.no/examples - Example 2

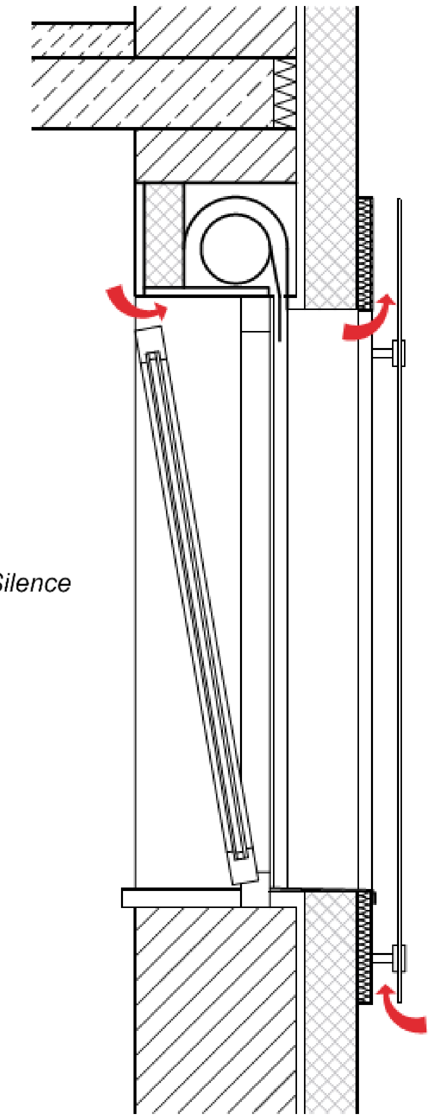
Façade improvement: Fixed glazing in front of windows (Example 003)

To reduce external noise intrusion into bedrooms, fixed glass panels can be installed. Glass panels are made of self-cleaning laminated safety glass, placed at an appropriate distance from the façade. Rotating ventilation slots provide permanent ventilation of the rooms. The glass elements overlap the window opening by approximately 25cm. These areas are filled with a noise reducing mineral fibre mat.
The fixed glazing in front of the windows lowers the noise by partially open windows up to 24dB.



Source: Magda Thomsen, Munich

Fixed glazing design



Fixed glazing design and detail, Middle Ring Munich

Example

The Middle Ring is one of the main arteries of the city of Munich. Approximately 64,000 vehicles travel daily on the Innsbruck Ring. In the absence of remedial measures, noise emissions associated with this traffic volume can result in a poor acoustic environment for residents.
In order to improve quality of living in ‘Mitetlerer Ring’, the noise protection concept was developed. This concept consists of several individual constructions, as follows:

- Noise-insulating sliding panels *(refer to example no. 002)*;
- Fixed glazing in front of the windows;
- Glazing of balconies – Westplatz in Leipzig *(refer to example no. 004)*; and
- Noise-protection building blocks *(refer to example no. 005).*

Further information: http://on-air.no/examples

Façade improvement: Glazing of balconies (Example 004)

On a noisy façade, balconies can be closed with a flexible curtain façade made of glass. Glass façades consist of a rotating carrying frame and a horizontal mullion-transom system as the upper edge. Clear glass elements can be formed without rungs. The final touches can be metallic shading elements with a specific pattern which allows each tenant to personalise the view and the amount of sunlight on the balcony.
The glazing of balconies can reduce noise levels by up to 20dB and improve residents' quality of living considerably.

Renovated building at Westplatz in Leipzig, Germany

Interior and exterior of balcony structure (left), rotating glass frame (right) at the Westplatz in Leipzig Germany

Example
The Middle Ring is one of the main arteries of the city of Munich.
Approximately 64,000 vehicles travel daily on the Innsbruck Ring. In the absence of remedial measures, noise emissions associated with this traffic volume can result in a poor acoustic environment for residents.
In order to improve quality of living in the 'Mitetlerer Ring', the noise protection concept was developed. This concept consists of several individual constructions, as follows:

- Noise insulating sliding panels *(refer to example no. 002)*;
- Fixed glazing in front of the windows *(refer to example no. 003)*;
- Glazing of balconies; and
- Noise protection building blocks *(refer to example no. 005)*.

Further information:
http://on-air.no/examples - Example 4

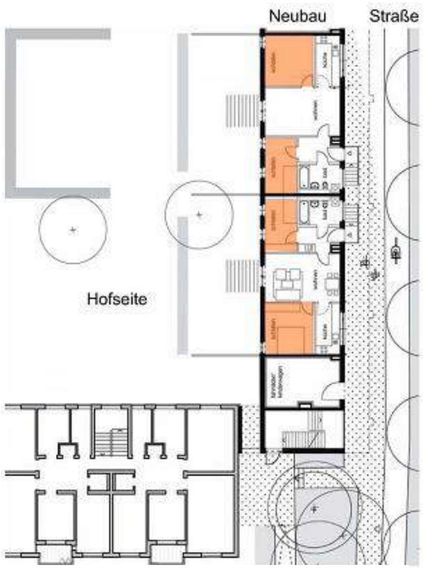
Noise-protection building blocks (Example 005)

New building structures, constructed specifically for noise reduction on existing buildings, can provide effective noise protection, creating a quiet façade and improving residents' quality of life considerably.

In the example of the Innsbruck Ring, Munich, a new noise protection has been built in the form of four five-storey residential buildings. These enclose the open courtyards and connect the existing buildings from north to south. The floor plans are divided into three zones, as follows:

- A building entrance oriented to the street with glazed arcades. The profile glazing shields against traffic noise and provides weather protection;
- Arcades connecting the apartments to the rest of the building structure; and
- Bedrooms and living rooms are oriented to the silent façades.

Detail of glazed arcades, Innsbruck Ring 70 and 72, Middle Ring, Munich



Source: Krieger Architekten, Samerberg

Source: LHM Vermessungsamt

Rooms oriented to the silent façade (left) and noise protection buildings blocks (right)

Example

The Middle Ring is one of the main arteries of the city of Munich. Approximately 64,000 vehicles travel daily on the Innsbruck Ring. In the absence of remedial measures, noise emissions associated with this traffic volume can result in a poor acoustic environment for residents.

To improve residents' quality of life in the 'Mittlerer Ring', the noise protection concept was developed.

This concept consists of the several individual constructions, as follows:

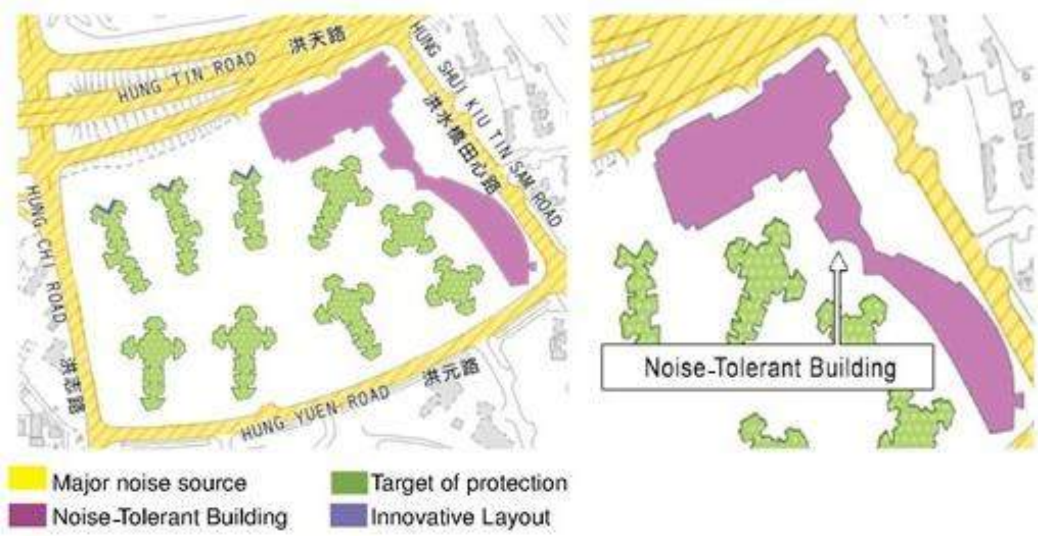
- Noise-insulating sliding panels *(refer to example no. 002)*;
- Fixed glazing in front of the windows *(refer to example no. 003)*;
- Glazing of balconies – Westplatz in Leipzig *(refer to example no. 004)*; and
- Noise-protection building blocks.

Further information:
http://on-air.no/examples - Example 5

Buildings as noise shields (Example 006)

Additional noise protection can be achieved by arranging the site plan to use buildings as noise barriers. A long building or a row of buildings parallel to a highway can shield more distant structures or open areas from noise.

In addition, a noise-tolerant building such as a multi-storey carpark building can be used to protect residential buildings from road traffic noise. Placing a noise-tolerant building between the road traffic and the residential building causes the noise in the ‘shadow zone’ to be reduced. This results in a reduction in the traffic noise affecting the residents.



Public Rental Housing Development at Hung Shui Kiu, Hong Kong

Aldrich Garden at Shau Kei Wan, Hong Kong

Source: Hong Kong Housing Authority

Example

1. Aldrich Garden at Shau Kei Wan, Hong Kong:
   A 30m high carpark (noise-tolerant building) acts as a noise-shielding structure for the residential buildings in the background. The noise reduction is approximately 5–9dB.

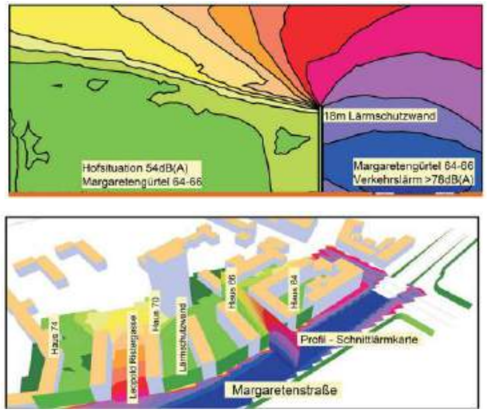
2. Public Rental Housing Development at Hung Shui Kiu, Hong Kong
   Commercial Centre (noise-tolerant building) of approximately 10m high, plus a 3m barrier wall on top of the building, serves as a noise-shielding structure to protect the residents at the back. Noise reduction is approximately 5–15dB.

Further information:
[http://on-air.no/examples - Example 6](http://on-air.no/examples)

Noise barriers and screens (Example 007)

Noise barriers or screens are an effective but very costly measure to reduce noise propagation alongside roads or railway lines. To function well, the barrier should obscure the direct line-of-sight between the source and receiver. The main requirement is that the barrier needs to be high and long enough. For the construction of barriers, a range of materials with different characteristics regarding absorption and reflection of sound is used.
In some cases where other solutions are not possible, very high transparent noise barriers and screens are built.

Glass noise screen at the Theodor-Körner-Hof: street (left) and courtyard view (right)



Source: City of Vienna

Noise situation after the implementation of the noise screen (above), vertical noise map (below)

Example

The Theodor-Körner-Hof is an urban residential complex in Vienna Margaret and lies directly on the heavily trafficked Margaret Street. The residential complex has 1,356 apartments and is the largest urban residential block in Margaret. The open building structure is perpendicular to the road, allowing propagation of sound. Therefore, approximately 90% of the residents were exposed to high noise levels, both day and night.

In 2007, an 18m high noise screen was built. The screen is made of glass, allowing enough light and brightness between the buildings. In the top row of the noise screen, photovoltaic systems have been installed. The achieved noise reduction is 23dB.

The protective noise screens improved the quality of living considerably, creating a quiet courtyard and common space for the residents. However, in the broader use of noise screens, these effects can be limited due to the sound reflection in areas with sensitive use on the opposite side of the barrier.

Further information:
http://on-air.no/examples - Example 7

Façade improvement: Double façade (Example 008)

Double façades can be used to control environmental noise propagation without the need for acoustic attenuation. When using a double façade, air enters the building through conventional open windows.

The acoustic protection is achieved by acoustically screening these windows by means of a secondary façade. Air enters the void between the two façades via a gap at the bottom of the outer, secondary façade.

The advantage of this type of façade is that standard windows can be used. It is also possible to form buildings with an interesting and unique appearance.

The drawbacks are clearly cost and space; for these reasons, this type of noise control measure is less common. It is also important to note that secondary façades can compromise the acoustic separation between two rooms when windows are open. Acoustic splitters/absorbers may be required to maintain the sound insulation when there are two open windows.

Double façades: Leeuw van Vlaanderen (left) and Science Park (right), Amsterdam, the Netherlands

Example

1. The project at Science Park was realised in 2008. The location is next to the Almere-Amersfoort railway line in Amsterdam. Some of the interesting (noise) aspects of this project are the use of double façades and noise screens to protect against railway noise.
2. Leeuw van Vlaanderen – This is a building from the 1960s which was renovated in 2005. It is situated parallel to the A10 highway behind guardrail Amsterdam-West, 10 feet behind the A10.

The use of a shielding gallery, a quiet side and a double façade are some of the elements of this project.

Further information:
http://on-air.no/examples - Example 8

Façade improvement: Louvred façade (Example 009)

Additional façade elements can be used to control traffic noise propagation.

The main function of a louvre is to allow the flow of air into a building while inhibiting the ingress of the elements such as rain and noise.

Acoustical louvres are used as part of the intake/exhaust air system of buildings, structures or equipment to help reduce environmental noise. They have a relatively large surface area which compensates for their lack of depth. Models are available in varying depths, percentage of open area and blade configurations, yielding various results in terms of pressure loss and noise-reduction performance.

Source: Betina Skovbro/John Seaman

Source: IBI Group

The [Hadyn Ellis Building](#) features louvred screens which wrap around the building and reduce noise from the street

Source: IBI Group

The screen serves as a venetian blind to improve privacy between the facility and nearby houses

Example

In 2008, Cardiff University, a member of the Russell Group of Universities, embarked on the development of a master plan known as the Maindy Road Campus. The construction of the Hadyn Ellis Building involved several laboratory-based research groups to be housed in one building, along with exhibition and conference facilities, a lecture theatre, seminar suites and office accommodations.

One of the challenges of the project was addressing the risk of incoming noise from the neighbouring road. To reduce the noise and maintain the required acoustic comfort levels within, a louvred screen wraps around the entire front of the building and incorporates acoustic absorbing material. In addition, the screen serves as a venetian blind to improve privacy between the facility and nearby houses.

On the outside, the block facing the housing is clad in coloured glazing which tonally responds to the brick and develops a language appropriate to the university. This is set against a backdrop of terracotta cladding, which complements the university's existing architecture.

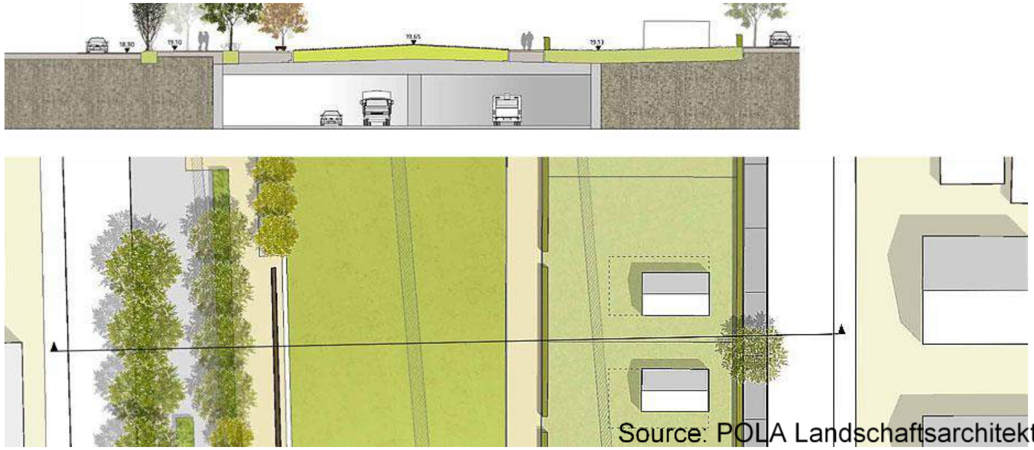
The building was completed in 2013 and was distinguished as 'Best Higher Education Building in Wales' at the BREEAM (Building Research Establishment Environmental Assessment Method) Awards in 2012.

Further information:
http://on-air.no/examples - Example 9

Tunnel – Highway A7, Hamburg (Example 010)

Increasingly, road designers are selecting tunnels as a suitable option due to their ability to reduce some environmental impact components, such as noise and air pollution, as well as visual intrusion of infrastructures. Tunnels are the most effective means of noise screening but also the most expensive.

Planned parks and small gardens at Stellingen (top) and Altona (bottom) tunnels



Sectional view (top) and top view (bottom) of one of the tunnels with new recreational use.

Example

The A7 is one of the longest, most frequently used highways in Germany and a significant connection between Scandinavia and Southern Europe. In the highway section which runs through west Hamburg alone, 152,000 vehicles pass by daily. Analysis of the future traffic growth has shown a great need for highway reconstruction and enlargement. To achieve optimal noise protection for residents while incorporating unique opportunities for urban development of new green spaces and residential areas, the reconstruction project of highway A7 – 'Hamburger Deckel' – was developed.

The highway A7 will be expanded by one lane in each direction and three tunnels (Schnelsen, Stellingen and Altona), with a complete length of approximately 3,500m.

Construction of the tunnels will minimise noise pollution in surrounding areas. Newly developed parks on the tunnel roofs and possibilities for development of new residential areas along the tunnels will significantly improve the quality of life in what are currently the loudest city districts in Hamburg.

Of the overall costs, approximately 57% are invested for the noise protection tunnels, 12% for noise barriers and in the region of 31% for the road construction itself.

Further information:
[http://on-air.no/examples - Example](http://on-air.no/examples)10

Speed limit of 30km/h on major roads (Example 011)

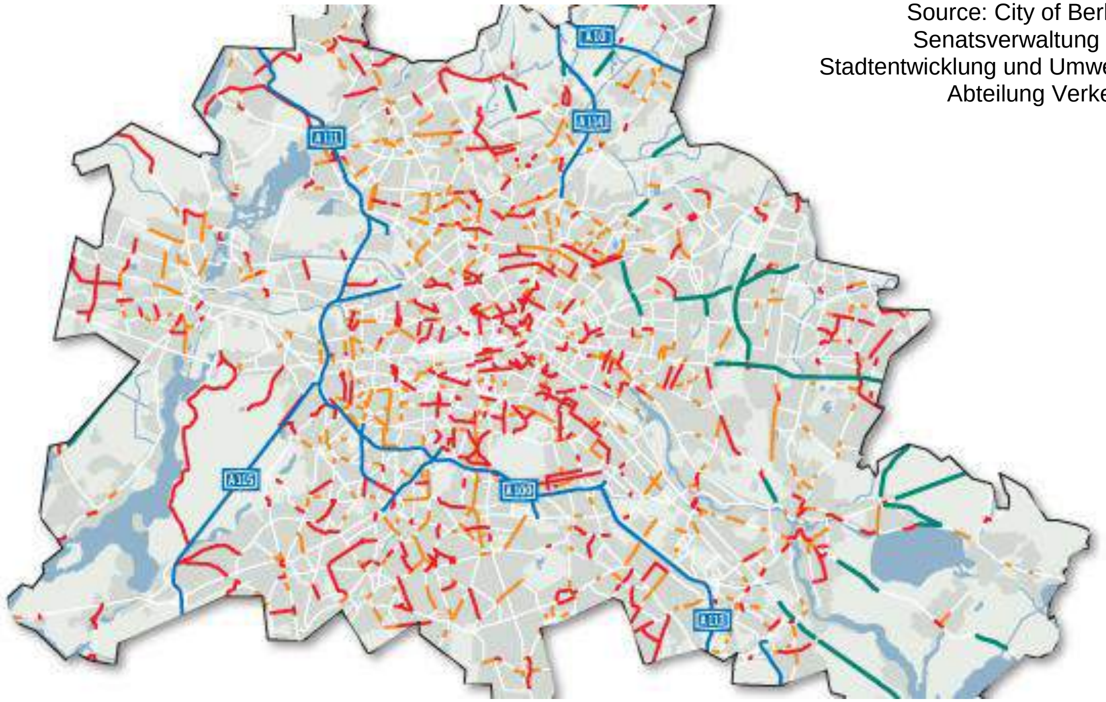
A speed limit of 30km/h is a simple and inexpensive way to reduce noise and has other positive results, including increased road safety, decreased air pollution and increased residential quality.

When the speed limit is lowered from 50km/h to 30km/h, the personal perception of noise-level reduction is high. In the case of pilot projects in Berlin, a measured reduction of the noise level was ‘only’ 1.4dB. However, the proportion of strong and extremely strong annoyance decreased by 26%. Similar effects were seen in studies in Rostock.

Example

In Rostock, the framework of the noise abatement plan examined the effects of speed reduction from 50 to 30km/h at night (2200–0600 h) on the two main streets. Assessment was conducted through traffic and noise measurements, surveys, etc. Noise measurements showed a decrease in the noise level between 1 and 1.5dB, while residents’ subjective feeling of annoyance decreased and their life quality increased. Based on the positive results, the City Council decided to introduce a permanent speed limit of 30km/h on both examined streets.

The Berlin Senate Department introduced a pilot project on six major roads in 1999/2000 where a speed limit of 30km/h at night was introduced. The pilot project involved computational screening of noise pollution, accompanied with traffic surveys, noise measurements and a survey of residents.



Source: City of Berlin, Senatsverwaltung für Stadtentwicklung und Umwelt, Abteilung Verkehr

On the examined roads, a significant reduction in traffic was detected (approximately 11–17% at night), and a noise reduction between 0.2 and 2.7dB was achieved.

The figure illustrates that on almost every route, there are sections with 30km/h – on roads marked in red, the speed limit of 30km/h is enforced all day; on roads marked in orange, this speed limit is temporary (night). On green roads, speeds of more than 50km/h are allowed.

To obtain the best results, the Senate recommended the following support measures: reduction of the lane widths, optical narrowing of the cross-section,

adjustment of traffic lights and speed monitoring.

Currently, approximately three-quarters of Berlin’s major roads (5,340km) have speed limits of 30km/h at night.

Further information:
[http://on-air.no/examples - Example](http://on-air.no/examples)11

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Solar energy and highway – Enclosures (Example 013)

The latest trend in highway noise mitigation is a combination of photovoltaics and noise protection. Solar cells are usually installed alongside road lanes in the form of photovoltaic noise barriers. Solar cells can also be placed on top of the existing noise protection tunnels and/or enclosures.

The main criteria in the selection of the location where this dual system can be combined are the age and condition of the existing structure, climate conditions and costs.

The Federal Highway Research Institute (BAST) created a nationwide cadastre of existing noise barriers to determine which of them are suitable for potential photovoltaic application.


Source: Evergreen Solar

Detail of a noise-protection tunnel with solar panels, Aschaffenburg, Germany


Source: Evergreen Solar

Noise-protection tunnel with a solar power plant on the roof, highway A3 near Aschaffenburg, Germany

Example

Construction of the 2.8km long noise-protection enclosure (tunnel) on highway A3 between Frankfurt and Würzburg in Germany was completed in 2005.

The construction of the tunnel was the best solution. Since the first houses are just 50m from the road, there was not enough space for the earth banks. In addition, noise barriers used to achieve necessary noise protection would have been too high and unstable in their construction.

On top of the tunnel, a photovoltaic power plant containing 16,000 solar modules from Evergreen Solar was installed in 2008. The photovoltaic power plant has a total length of 2.7km and produces 2.6 million kilowatt hours of electricity per year.

The estimated €11 million investment costs are expected to be amortized within 16 years.

On the German highway network, there are several suitable areas for solar power generation. However, they are rarely used for this purpose.

Further information:
[http://on-air.no/examples - Example](http://on-air.no/examples)13

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Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

Traffic bans for certain types of vehicles (Example 015)

The composition of traffic in terms of vehicle categories is important in determining noise levels.

On most urban roads, heavy vehicles only account for a small percentage of the total traffic. In combination with the usually higher speed of light vehicles, the effect is that the light vehicles generally dominate the noise emissions. On most high-speed roads, particularly motorways, the speed of light vehicles is considerably higher, and these therefore also dominate the noise emission in these situations, even though the percentages of heavy vehicles are often fairly high.

At night, the peak levels caused by the heavy vehicles represent noise events which may wake people living along the road or cause alterations to their sleep pattern.

A temporally and spatially limited ban for certain types of vehicles, such as night banning, of heavy vehicles brings different results on urban roads and highways. Since the proportion of heavy vehicles in the overall noise level on urban roads is low, even at night, a traffic ban leads to a reduction of L_{eq} of approximately 1dB. On rural roads, the reduction potential is between 2 and 3dB. However, the number of noise peaks is greatly reduced by this measure.

Trucks waiting at a motorway lay-by during driving ban.

Example
On weekends and public holidays, driving bans for heavy goods vehicles (HGVs) are in force in Germany, Austria and Switzerland. These traffic bans apply to different time periods and gross vehicle weight: Whilst Switzerland bans all vehicles over 3.5 tonnes for the whole day of Saturday (midnight to midnight), Germany and Austria only ban vehicles with more than 7.5 tonnes. The ban time is from midnight to 2200 h in Germany, in Austria the ban starts at 1500 h on Sundays until 2200 h on Saturdays.

Such measures are sometimes also used in France, Italy, Luxembourg, Romania, Poland, Liechtenstein, Greece, Slovenia, the Czech Republic and Hungary.

A night driving ban is in force between 2200 and 0500 h in Switzerland for HGVs over 3.5 tonnes and in Austria for HGVs over 7.5 tonnes.

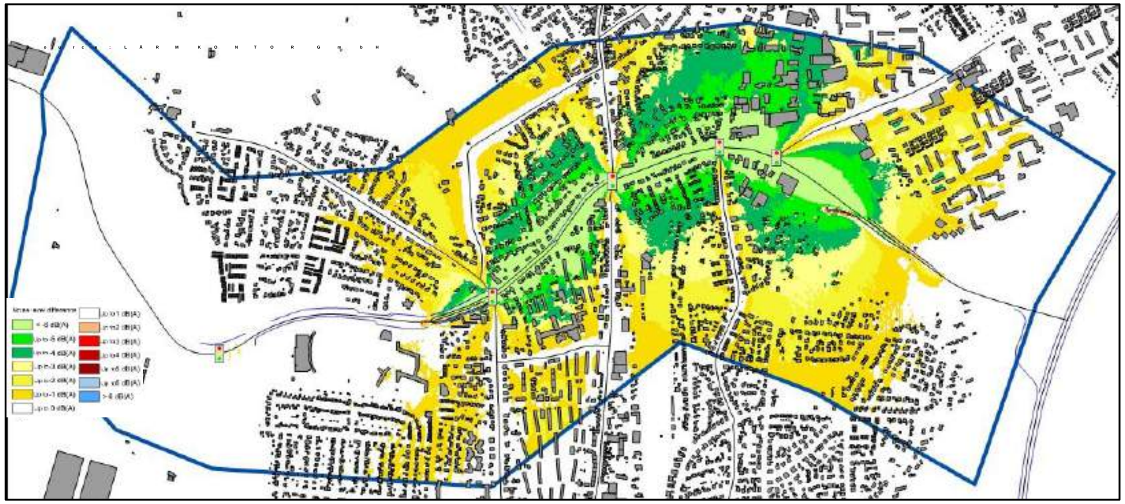
Further information:
http://on-air.no/examples - Example 15

Detailed planning for Cherbourger Street, Bremerhaven, Germany (Example 016)

Detailed planning is an integral part of all highway construction and reconstruction projects. Environmental protection elements have an important role in the decision-making process. In some projects, existing and potential noise and air pollution can be decisive in the selection of the final corridor.

Cherbourger Street in Bremerhaven, Germany, is the main connection between the port and highway A27. With a high percentage of heavy goods vehicles, it is burdened with high noise (78dB (Lr) in the day and 72dB (Lr) at night) and air pollution levels.

The final solution: The tunnel south from Cherbourger Street (marked red) with the east and west ramp (marked blue)



Noise map illustrating improvements along the current alignment

Example

The Port Tunnel on Cherbourger Street in Bremerhaven, Germany, is the result of a planning process spanning many years. The plans for efficient port services in the field of Cherbourger Street began in 1997 during the fourth stage of expansion of container terminal IV. In the following years, various versions were developed, discussed with the citizens and political decision makers and partly rejected. Amongst these were two northern bypasses, several tunnel solutions such as a short tunnel and the tunnel route under Cherbourger Street and a partly covered road in the cut.

The tunnel is to run from east to west and will be located south of Cherbourger Street. It will serve as an efficient road link, connecting the international port and business parks located close to the port with the highway A27.

The two-lane road tunnel will be constructed using an open cut construction method, together with all entrance and exit ramps, two operation buildings and 10 escape staircases. The structure will be 1,195m long and will consist of a tunnel tube with two-way traffic; at the eastern end, this will divide into two separate tubes where the respective traffic flows are in one direction. The total length will be 1,848m (north side) and 1,659m (south side). The tunnel is scheduled to be completed by the end of June 2018, and it will considerably reduce the traffic volume around Cherbourger Street.

Further information:
hhttp://on-air.no/examples - Example 16

Handling of noise in a policy package (Example 017)

Policy packages are structures used to combine different policy measures and address multiple objectives. In Norway, they have been used for the integration of land-use and transport-system development in all of the larger urban regions. The environmental package in Trondheim is one of these; one of its goals is to reduce the number of people impacted by traffic noise by 15% by 2018 (Municipality of Trondheim, 2008)[1]. An investment of €200 million will be made on noise mitigation between 2011 and 2024. Before the policy package was implemented in 2008, both indoor and outdoor noise levels were mapped. The central areas and those close to the main roads were the most exposed.

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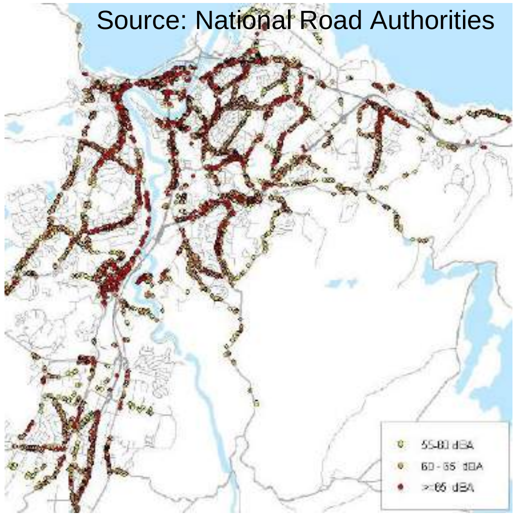
Noise barrier on a major road, south of Trondheim



Outdoor noise levels for 2007, Trondheim

Example

Noise is addressed in different ways in Trondheim. Firstly, barriers are installed (in accordance to the noise mapping) and façade insulation is used for specific houses in central areas. Secondly, several of the road projects financed through the policy package (including a tunnel) are considered to reduce noise in specific areas. Thirdly, regulation is used to direct car drivers to certain roads, thereby reducing traffic and noise on others. Regulation (e.g. toll-road and parking schemes) is also used to reduce traffic volumes in general, potentially also reducing noise levels.

When integrated in a policy package, the handling of noise in Trondheim is high on the political agenda. It is part of the overall urban development strategy. The environmental package illustrates the challenge of conflicting aims within policy packages: To reduce climate gas emissions, Trondheim aims for urban intensification. With the concentration of new dwellings in noise-exposed central areas, the number of people affected by noise is expected to rise (Municipality of Trondheim, 2012).

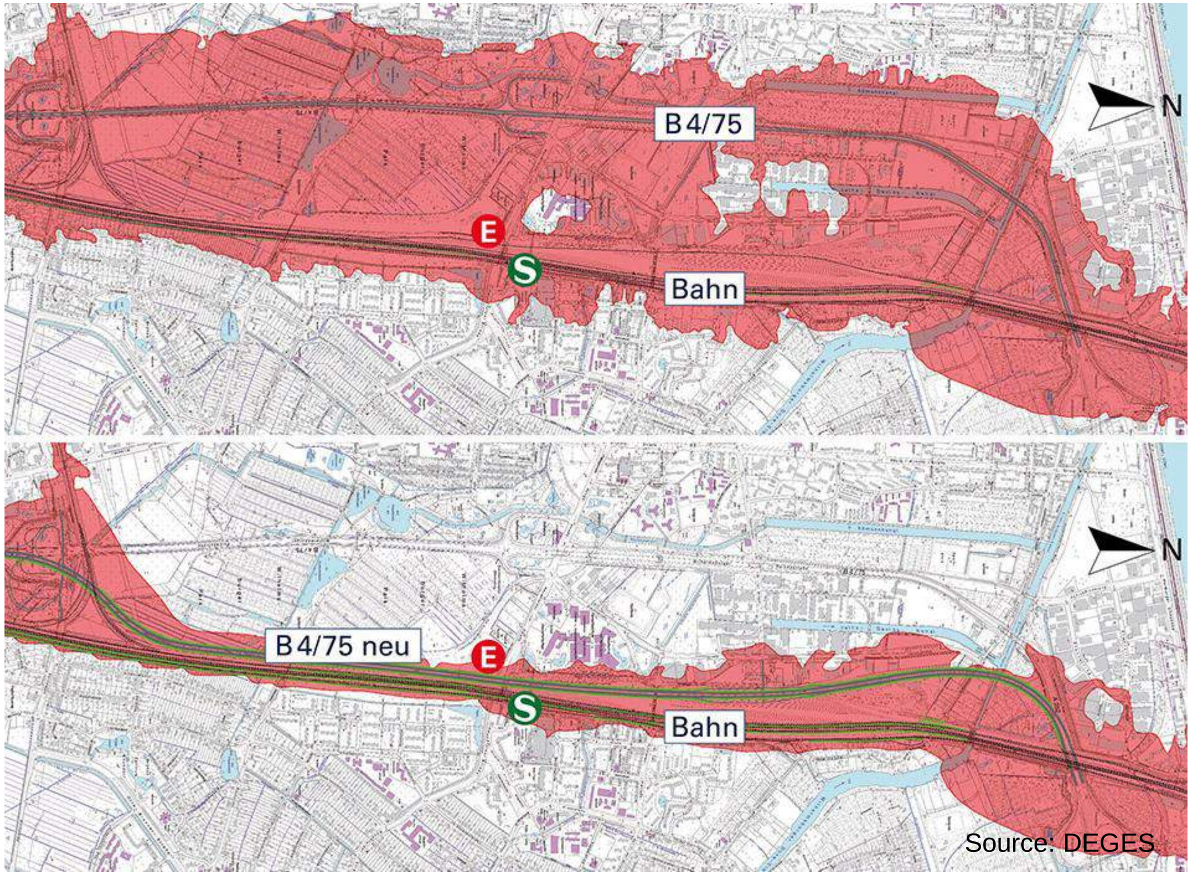
Further information: [http://on-air.no/examples - Example 17](http://on-air.no/examples)

[1] In relation to 2007 numbers.

Relocation of Wilhelmsburger Reichsstraße – B75 Hamburg (Example 018)

Noise control at source has proven to be the most cost-effective form of noise mitigation. Concentrating noise sources such as railway tracks and highways allows joint solutions to the noise problem.

Example
The Wilhelmsburger Reichsstraße (federal highway B75) is a major traffic artery in the Southern Elbe area of Hamburg. Approximately 55,000 vehicles travel on this route daily; roughly 10% of them are trucks.



The red areas show the current noise propagation of 59dB a day (top), a significant reduction in the noise propagation after the relocation of B75 (bottom)

The B75 was not designed for this amount of traffic and does not meet modern safety standards (the route is too narrow). Moreover, it is a significant source of noise, and in the spatial context, divides the Wilhelmsburger Island into two parts.

In the upcoming restoration of the route, most of these problems will be solved by a complete relocation of the corridor 400m east next to the rail tracks. The relocation will bring several benefits:

- Safety: Emergency lanes, wider driving lanes and guardrails will reduce the risk of accidents;
- Less noise: Noise barriers will reduce road and rail noise directly at the source;
- Greenness: The new International Garden Exhibition park and green areas give a special quality to the Wilhelmsburger Island; and
- Improved quality of living: The lower noise level will increase residents' satisfaction and the relocation will allow neighbourhoods to grow back together.

In the first stage of the construction, the old noise barriers (1.5–3.5m) along the railway tracks will be replaced with modern 5.5m high barriers. In the second stage, the B75 will be relocated alongside the railway tracks. In the future, the B75 will continue to serve as an important connection between southern suburbs and the city core of Hamburg.

Further information:
http://on-air.no/examples - Example 18

Noise reduction through green façades (Example 019)

When the building façades on both sides of a street are of hard material, the noise from road traffic will propagate in a zigzag pattern horizontally across the street. It will also reflect vertically upwards towards the ceiling level. These reflections increase the overall noise. One way to reduce such reflections is through green façades. The level of attenuation will depend on the distance between the façades on each side of the street, the number of reflection paths, and the attenuation of each path.

Housing surfaces, covered with vegetation, reduce noise at each reflection. Such vegetation can be placed either on the house front facing the noise source or on the short sides of apartment buildings (refer to the following figure). The underlying logic of the latter approach is that while the backyards of adjoining housing quarters protect well against noise, openings between buildings will reduce the noise protection (e.g. in backyards).

However, green façades are costly. If irrigation systems are not ventilated/constructed properly, they can lead to humidity with associated problems. More often, the façade is a habitat for bacteria/fungi and other organisms that are beneficial, but there is also a small possibility that the façades could become home to insects that one would need to get rid of.

Examples of module-based green façades

Example

Two different techniques can be described for the greening of façades. Firstly, there is vegetation, e.g. ivy, climbing up the housing façade. The disadvantages of this approach are that it takes time before the vegetation reaches a sufficient height and that it hinders maintenance of the façade.

Secondly, a module system could be erected using steel grids. To avoid moisture on the house wall, space is maintained between the vegetation and the façade. In a research project, the noise-reducing effects of green façades were calculated. In situations where the green façade faced a road with traffic, the noise reducing effect was found to be 1dB L_{den} (Klæboe and Veisten, 2014).

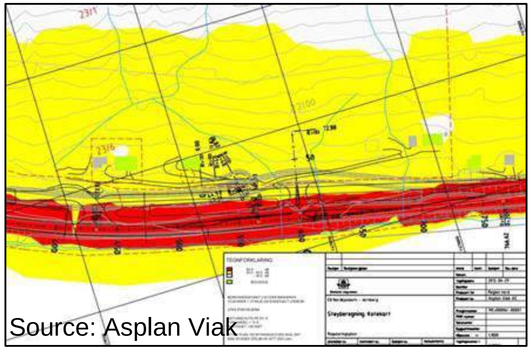
When the green façade was on a side wall between buildings (e.g. the entrance of a backyard), the effect was 4,5dB L_{den}.

Example of green façade

Further information:
[http://on-air.no/examples - Example](http://on-air.no/examples)19

Management of noise through planning zones (Example 020)

The way in which dwellings and workplaces are located around existing roads influences people's exposure to noise. This highlights the benefits of integrated planning, connecting the use of new buildings to the existing noise values at a given location. Cautious municipal planning in accordance with such principles provides an effective measure to reduce exposure to road noise for both dwellers and workers.



Source: Asplan Viak

Example of noise zones along a road

Noise source	Noise zone			
	Yellow zone		Red zone	
	Outdoor noise level	Outdoor noise level during the night period 23 – 07	Outdoor noise level	Outdoor noise level during the night period 23 – 07
Road	L_{den} 55 dB	L_{5AS} 70 dB	L_{den} 65 dB	L_{5AS} 85 dB

Outdoor limits for road noise (yellow and red zones) Source: Modified after T-1442/2012

Example
In Norway, limit values have been set for the handling of noise in land-use planning through national guidelines (T-1442/2012). Road noise is one of several noise sources considered. In the guidelines, land is divided into three zones: red, yellow and green. Within each of these, limit values have been established for both indoor and outdoor noise. **The red zone** is the area closest to the noise source. Here, the highest limit values are allowed (refer to figure), but there are also limitations in relation to which purposes are recommended. Buildings intended for noise-sensitive purposes are to be avoided in red zones.

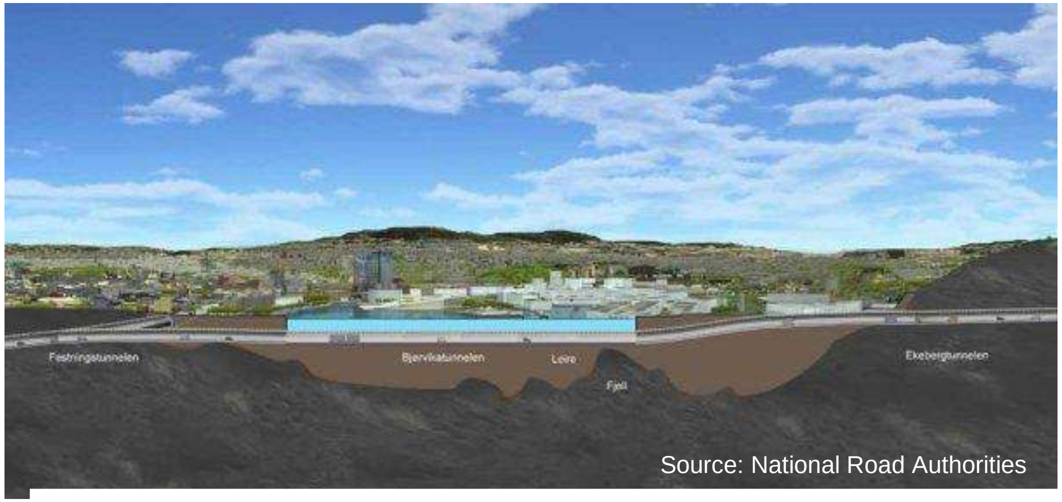
Within the **yellow zone**, the limit values are lower. Here, structures intended for noise-sensitive purposes could be accepted, providing that documentation of mitigating measures giving acceptable noise values at the location is collected.
The green zone describes areas where one wishes to keep noise at a minimum, such as in shielded city parks or natural parks. The guidelines are not legally binding, but substantial deviation may result in objections from national authorities (stopping the planned activity until an agreement has been reached).

Further information:
http://on-air.no/examples - Example 20

Urban districts relieved from noise exposure by road tunnels (Example 021)

Road tunnels are built for several reasons. In addition to goals of increasing traffic efficiency, the reduction of traffic's negative side effects on the surface is a typical argument for new construction. Hence, road tunnels are built to reduce the local population's exposure to traffic accidents, emissions and road noise. With traffic relocated underground, new opportunities open for urban development on the surface.

The redevelopment of Bjørvika tunnel



Cross-section of Bjørvika tunnel

Example

In Oslo, Norway, there has been a long-term political goal to redevelop the seafront around the central train station. This involves the creation of a whole new urban landscape. Important cultural institutions are being relocated in the area, alongside a large number of new dwellings and workplaces. Such a change would not have been possible without extensive restructuring of the road system. This means that the new urban development requires the surface to be redistributed for purposes other than car driving and the area being relieved from noise and traffic emission exposure. The most important measure in this regard has been the creation of the Bjørvika tunnel, a 675m long immersed tunnel on the seabed.

The tunnel, illustrated by the green line in the figure on the left, was opened in 2010. While Norway has many subsea tunnels bored through bedrock, the Bjørvika tunnel is the first lying on the seabed.

With a major road situated underground, traffic volumes in the Bjørvika area have been reduced substantially. The new urban district, which is in the making, is characterised by compact city development; dwellings and workplaces are substituting the former traffic machine at the seafront.

Further information:
http://on-air.no/examples - Example 21

Noise control using barriers, speed reduction and porous asphalt (Example 022)

Highway E4 passes close to residential buildings near Husqvarna in Sweden. Over the past 15 years, there has been a large increase in traffic, which has also resulted in increased noise levels at residential buildings. On the background of complaints from residents, in 2008, the Swedish environmental court decided that the national road administration should reduce noise levels by 10dB at the façades of residential buildings.

Calculations showed that a very long, high noise barrier was needed to fulfil the 10dB requirement. Cost-benefit analysis showed that this was an expensive solution. Instead, a combination of the following measures would be used:

1. A low noise barrier;
2. Noise-reducing two-layer porous asphalt on a 2.8km long section. The performance of the porous pavement is monitored by Close Proximity (CPX) noise trailer measurements every year; and
3. Speed reduction from 110 to 90km/h. Signs have been erected stating 'Reduced speed because of noise'.

The noise abatement measures were implemented in 2010.
Further information:
http://on-air.no/examples - Example 22

Source: Danish Road Directorate


Source: Danish Road Directorate


Source: Danish Road Directorate

Source: Danish Road Directorate

The Melbourne Noise Tube (Example 023)

Some years ago, a new 6-lane motorway called the 'City Link' was constructed in Melbourne, Australia. This connects downtown with the airport. On a long section, the new motorway is constructed on a bridge crossing existing roads.

At one location, the motorway bridge passes two 20-storey residential buildings and some large green areas. The noise design criterion for the highway was that a noise level of 63dB was not to be exceeded at the façade of residential buildings.

It was decided to construct a noise screening that partly covers the motorway facing the residential buildings. This noise barrier has the local nickname 'the Noise Tube'. At the four top floors of the residential buildings, it was also necessary to provide façade insulation in order to fulfil noise guidelines.

Further information:
http://on-air.no/examples - Example 23


Source: Danish Road Directorate


Source: Danish Road Directorate


Source: Danish Road Directorate

The picture can't be displayed.

Noise barriers constructed in cement concrete (Example 025)

The acoustic function of noise barriers is briefly described in Section 3.7.2 – Noise abatement under propagation of the guidance book.

Noise barriers constructed of cement concrete can be given different visual appearances by the use of structures and 'prints' on the surface, as well as by using different colours.

Examples:
Concrete noise barrier in Tallinn, Estonia, with a profiled surface.

Concrete noise barriers in Melbourne, Australia, with 'text prints', different colours and a transparent top barrier.


Melbourne / Source: Danish Road Directorate


Melbourne / Source: Danish Road Directorate


Tallinn / Source: Danish Road Directorate


Melbourne / Source: Danish Road Directorate


Tallinn / Source: Danish Road Directorate

Green noise barriers (Example 026)

Various strategies for the adaptation of noise barriers and embankments to urban and rural surroundings can be used. One strategy is the planting of trees and other vegetation so that the noise barrier fits in with the surrounding environment.

Noise barriers with a green appearance are considered attractive at some locations. The road can be given a new visual quality through planting. Climbing plants or bushes, growing up against a barrier, will make the barrier less conspicuous. Planting along the base of a barrier in plant boxes can break up the monotony of the barrier and make a high barrier appear lower.

It is necessary to give vegetation good growth conditions, including access to sufficient water. At dry locations, irrigation systems may be needed. Vegetation must have plenty of soil to grow in and protection from salt water used in the winter maintenance of the road.

Examples:
Top: Absorbing steel noise barrier with a steel grid to support vegetation on the barrier at highway M14 in Denmark

Middle: Brown wooden noise barrier adapted to the green surroundings on highway M11 in Denmark

Bottom: Concrete barrier with vegetation on highway 680 in California, USA

Further information:
[http://on-air.no/examples - Example 26](http://on-air.no/examples)


Source: Danish Road Directorate


Source: Danish Road Directorate


Source: Danish Road Directorate

A noise barrier with two front sides facing the road and the residents (Example 027)

The noise barriers have two front sides: one facing the road and one facing the neighbours and the urban environment adjacent to the road.

The drivers will possibly pass the noise barrier at least twice every day and the people living at the other front side will have to look at the noise barrier every day as long as they live near the barrier.

In the design phase of noise barriers, it is important to prioritise both sides of the noise barrier equally. The requirements for the barrier design might be different when viewed from the road and drivers' point of view as opposed to the residents' perspective. Therefore, a solution may be to design a barrier that has two different appearances, i.e. as viewed from the road and by the residents.

Source: Danish Road Directorate

Source: Danish Road Directorate

Example:
The images show the solution selected at the M3 motorway around Copenhagen.
The front side facing the road is constructed of steel and some glass sections. At the front side facing the residents, wooden ribs have been placed vertically on the barrier to allow plants to grow on it.

Further information:
http://on-air.no/examples - Example 27

Source: Danish Road Directorate

Tall noise barrier integrated as an element in urban sculpture (Example 028)

Just north of the Melbourne 'Noise Tube' *(refer to example no. 023)*, a three-lane motorway ramp has been constructed. The ramp passes very close to one- to four-storey residential buildings. In order to provide noise screening for these buildings, a 10m high yellow noise barrier has been erected.

Adjacent to the ramp, a rainwater basin has been constructed. Some large red steel posts with a length of more than 10m have been mounted. Together, the yellow noise barrier, the water basin and the steel posts exhibit remarkable sculptural performance in the urban environment.

Further information:
http://on-air.no/examples - Example 28


Source: Danish Road Directorate

Transparent noise barriers (Example 029)

Transparent material can be used where a see-through barrier is needed, e.g. when a barrier is situated close to a building, and thus significantly blocks the residents' view. These materials are best suited to urban surroundings and will often mean that the noise barrier is relatively anonymous in appearance. However, they can also be used in the countryside to allow road users to see a view or a landmark.

Glass or another transparent material can also be used to reduce the visual effect of a noise barrier in an open landscape. Transparent noise barriers require cleaning to prevent them from appearing soiled and dull. The acoustic function of noise barriers is described in Section 3.7.2 of the guidance book.

Examples:
Top: A transparent section of a steel noise barrier in the Netherlands

Middle: Transparent noise barriers with steel frames along a motorway and ramp in Rome, Italy

Bottom: A transparent noise barrier with steel posts on an embankment along a motorway in Denmark

Further information:
[http://on-air.no/examples - Example](http://on-air.no/examples)29

Large steel noise barrier bending over the road (Example 030)

The motorway connection between Vienna Airport in Austria and the city centre passes by a residential area. A tall steel noise barrier has been constructed. The barrier bends over the road in order to increase the noise reduction by having the top of the barrier as close to the noise source as possible. Steel plates with small holes are used to make the barrier noise absorbing.

A green belt of vegetation is situated between the barrier and the residential buildings.

Further information:
http://on-air.no/examples - Example 30


Source: Danish Road Directorate

Source: Danish Road Directorate


Source: Danish Road Directorate


Source: Danish Road Directorate

Graffiti-free barriers with wooden slats (Example 031)

Dirt, weather and graffiti are the most common challenges related to noise barriers. In particular, graffiti on noise barriers can be a problem. Effective methods for removal are available, but it is resource-consuming to inspect noise barriers and remove graffiti.


Source: Danish Road Directorate


Source: Danish Road Directorate

Noise barriers are very conspicuous elements along a road, and the large visible surfaces attract graffiti painting. To avoid graffiti, as well as to improve the general aesthetic quality of a standard noise barrier, the Danish Road Directorate is now using wooden slats mounted on the roadside and neighbouring side of a standard barrier. After three years, no graffiti is evident on any of the noise screens with wooden slats. The primary structural elements, consisting of foundations, steel columns and bolt groups, have a lifespan of at least 50 years. The secondary structural elements, which can be removed and replaced, have a life span of at least 25 years; however, the wooden slats are only expected to last 15 years or more.

Further information:
http://on-air.no/examples - Example 31.


Source: Danish Road Directorate


Source: Danish Road Directorate


Source: Danish Road Directorate

‘Green Noise’ – Reduced indoor noise levels and improved air quality (Example 032)

Fredensgade is a highly traffic-congested street in the central part of Copenhagen. Housing in Fredensgade underwent an extensive renovation. In this context, the ‘Green Noise’ project was carried out, with the aim of finding a relatively simple, non-space-consuming, technical solution to reduce traffic noise indoors and provide a fresh clean air supply for the dwellings.

The main elements of the project are as follows:

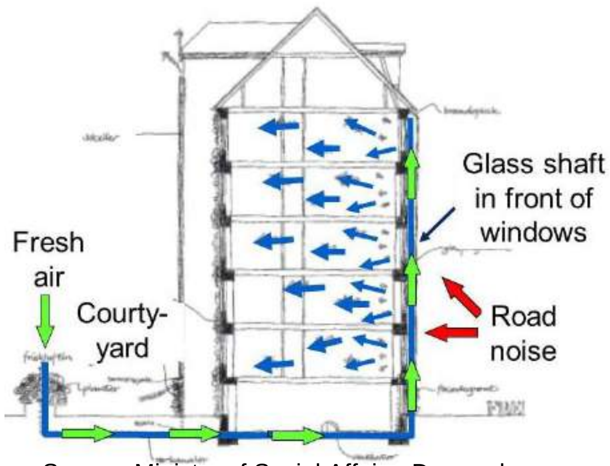
- Façade noise screen in the form of a glass shaft and fresh air supply towards the street;
- Solar panels for an additional power supply for fans; and
- Heat recovery.

Source: Danish Road Directorate

A solution was chosen to place a soundproof glass shaft in front of selected windows on the street façade; according to the project report, this would meet all of the criteria. The design is outlined in the figure to the right. Residents can obtain fresh air by opening the window, and the soundproof glass shaft in front of selected windows contributes to passive solar heating when the sun is shining. The air in the glass shaft comes from the courtyard where the air is cleaner than the air from the street.

One criterion was that internal noise levels, in the renovated house, from road traffic were required to meet limits specified within the Building Regulations, a maximum of 33dB L_{den} indoors with the windows closed.

Source: Danish Road Directorate



Source: Ministry of Social Affairs, Denmark

Reduced indoor noise

Pre- and post-measurements of the façade insulation were carried out in two apartments: one on the ground floor and one on the second floor, with closed and open windows, respectively.

On the ground floor, the indoor noise level was reduced by 11dB with closed windows and by 17dB with open windows (behind the glass shaft). On the second floor, the indoor noise level was improved by 7dB with closed windows and 15dB with open windows (behind the glass shaft).

Further information:
[http://on-air.no/examples - Example](http://on-air.no/examples)32

Non-reflective noise barriers (Example 033)

Noise barriers can reflect noise. This may have the unfortunate consequence of increasing noise levels for people living on the opposite side of a road.

How much the noise level on the other side of the road will be increased depends on site conditions, the height of the barrier, and the nature of the building opposite it. If these consist of an unbroken line of multi-storied buildings, the erection of the barrier will form a "closed" canyon, in which the sound is repeatedly thrown back and forth. Sound reflection can theoretically increase the noise level by up to 6dB when there are reflecting surfaces on both sides of a road. For low, open housing areas, the noise level on the opposite side can theoretically be increased by up to 3dB due to reflections form a barrier.

If noise screening is established on both sides of the road, the noise can be reflected back and forth between the barriers.

The attenuation provided by the barrier is not as effective for reflected noise when compared with the direct noise. Total attenuation provided can be significantly reduced. However, the further the reflecting surface is from the road, the lower the contribution from reflection will be.

There are different solutions to reflection problems. These solutions may result in different visual impacts, which can make their mark on the surroundings of the road. The barrier can be erected at a slant so that the noise is reflected up into the air, where it will not disturb anyone.

Vegetation can be planted between the road and the barriers. Vegetation will disperse the noise, both before and after reflection from the noise barrier. Vegetation should be as dense (all year), broad and high as possible.

Finally, there is a third solution, in which a noise barrier is provided with sound absorbent material on the side facing the road, so that reflection is reduced or entirely eliminated.

Further information:
http://on-air.no/examples - Example 33


Source: Danish Road Directorate


Source: Danish Road Directorate

Grants for façade insulation of dwellings (Example 034)

The Danish Road Directorate has a scheme for façade insulation of residential buildings. The scheme includes grants for façade insulation along existing roads and new roads.

Façade insulation typically includes changing windows and doors to new and better noise-reducing types (and often heat insulation, saving energy).

Grants can be given to noise insulation of bedrooms, living rooms and kitchens with a dining table. An indoor noise reduction of at least 5dB must be obtained and the resulting indoor noise level must not exceed 33dB (L_{den}).

The Road Directorate does not carry out work on private properties. Instead, the Road Directorate contacts the owners of the impacted dwellings and offers grants for noise insulation. If the owners accept the offer, the procedure is as follows:

1. An acoustical consultant inspects the building and describes what kind of noise insulation has to be carried out;
2. The owner gets a price for the work from a private contractor;
3. The Road Directorate has to accept the the proposed solution for façade insulation and the price;
4. The owner orders the contractor to carry out the work;
5. An acoustical consultant inspects and approves the work carried out;
6. The owner pays the contractor; and
7. The owner sends the invoice to the Road Directorate for reimbursement.

They do not give grants to unlimited large insulation expenses. The maximum grant that can be obtained is €16,800 including VAT per dwelling (price level 2015). The grant depends on the actual noise level as can be seen in the following table. It is not possible to obtain grants with a façade noise level below 63dB (L_{den}).

Noise level on façade (L_{den})	Percentage grant of total costs
>73dB	90%
68–73dB	75%
63–68dB	50%

The Road Directorate has carried out a minor survey to evaluate the scheme for noise insulation for dwellings exposed to noise over 68dB (L_{den}) at the façade.

It showed that 90% of the respondents indicated that the noise insulation had improved their housing situation from ‘moderate’ to ‘very much’. Approximately two-thirds of the respondents were surprised by the positive effect of noise insulation. Nearly two-thirds were very or highly annoyed by traffic noise indoor before the noise insulation, while approximately one in ten were very or highly annoyed after the noise insolation.

Further information:
http://on-air.no/examples - Example 34

An example where new windows are provided with sound proof glass. Compared with the original windows it gave a noise reduction of 13 dB in the living room

Enlarging ring road around Copenhagen from 4 to 6 lanes (Example 035)

A combination of measures of noise abatement may be necessary to fulfil noise limit values decided for a road project.

Due to the increase in traffic, it was decided to widen the Motorway 3 (M3) from four to six lanes on a 17km long section. The traffic volume was 90,000. The M3 is an urban motorway, passing through a heavily populated area. 14,000 dwellings are located in a belt of 500m on both sides of the motorway. Prior to the widening of the M3, old 1.5–2m noise barriers were in place. If the old low noise barriers along the M3 were kept until 2010, there would have been 6,300 dwellings exposed to more than 55dB ($L_{Aeq,24}$).

On the background of the Environmental Impact Assessment (EIA) and an evaluation of cost effectiveness, it was decided in this specific project to use 60dB ($L_{Aeq,24}$) as the noise guideline. 60dB represents a significant reduction in noise for many of the dwellings. In order to achieve 60dB, the following measures have been implemented:

1. 17,900m of noise barriers
2. Noise reducing thin layer pavements

Where these measures have not been enough to achieve 60dB, façade insulation has been offered to the owners. After the M3 was widened and new noise barriers constructed, only 2,200 dwellings were exposed to noise higher than 55dB.


Source: Danish Road Directorate


Source: Danish Road Directorate

Reduced noise annoyance

A pre-, post- questionnaire study showed that among the people living close to the M3, there has been a reduction in the perceived noise annoyance. The total percentage of very and extremely annoyed respondents decreased from 37% to 16%. The total percentage of slightly annoyed and not at all annoyed increased from 33% to 57%.

Further information:
http://on-air.no/examples - Example 35

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